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NOISE IMPACT INVENTORY OF ELEVATED STRUCTURES IN U.S. URBAN RAIL RAPID TRANSIT SYSTEMS

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INTERIM REPORT

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16. Abstract

This report presents an inventory and impact assessment of the noise radiated by trains operating on 253 km (157 miles) of elevated structure in nine U.S. urban rail rapid transit systems. The structures are classified into 17 different categories, and noise emission characteristics are determined for each type, based on field measurements and/or published data. Day-night average sound levels (L_{dn}) are estimated for wayside locations near the elevated structures, and population data are used to evaluate noise impact in terms of the Sound Level Weighted Population (LWP).

The results indicate that approximately 384,300 people at residential locations in the U.S. are exposed to noise from rail transit operations on elevated structures. The total LWP was determined to be about 646,000. The noisiest type of structure - open deck (wood tie), carrying jointed rail on steel girders - was found to account for about 91 percent of the total nationwide noise impact.

17. Key Words
Noise, Rail Transportation, Urban Rail Noise, Elevated Structure Noise, Noise Impact

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PREFACE

This report presents the results of the third task of a five-task program dealing with the reduction of noise from elevated structures in use in U.S. rail rapid transit systems. This report was prepared by Bolt Beranek and Newman Inc. (BBN) under contract DOT-TSC-1531, as part of the Urban Rail Noise Abatement Program sponsored by the Office of Technology Development and Deployment, Office of Rail and Construction Technology of the U.S. Department of Transportation's Urban Mass Transportation Administration. This Noise Abatement Program, which is being managed for UMTA at the Transportation Systems Center, has the objectives of assessing the noise produced by urban rail transit operations and of appraising corresponding noise reduction methods and the associated costs.

Drs. Leonard G. Kurzweil and Robert P. Kendig of the Transportation Systems Center served as technical coordinators for the efforts leading to this report. An advisory board constituted by the American Public Transit Association and headed by Mr. Theodore S. Gordon provided much of the background information relating to the transit systems surveyed. Amman & Whitney, Consulting Engineers, assisted in the collection of physical inventory data; Mr. Samuel Weissman directed the Amman & Whitney tasks.

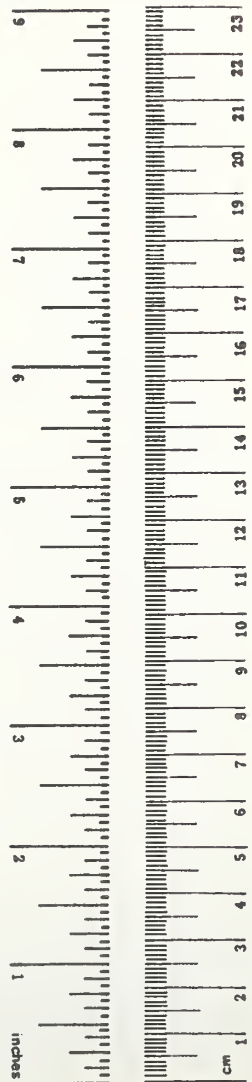
The author gratefully acknowledges the assistance of his colleagues, including Dr. Eric E. Ungar for overall direction and careful report review, Mr. Christopher W. Menge for his assistance with regard to field measurement planning, and Messrs. Paul S. Rotker and William F. Cote for the field measurement and data reduction programs.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

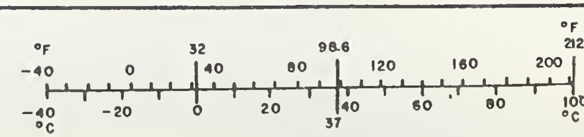
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

This report presents an inventory and impact assessment of the noise radiated by U.S. urban rail rapid transit elevated structures due to trains passing on these structures, insofar as this noise is experienced by nearby community residents. The report provides an overview of the noise contributions from the various types of structures in existing or planned U.S. transit systems and thus can serve as a basis for selecting structure types for which noise abatement would be most desirable.

This inventory includes approximately 253 km (157 miles) of elevated structure, maintained by the following U.S. transit properties:

- Metropolitan Atlanta Rapid Transit Authority (MARTA)
- Bay Area Rapid Transit District (BART)
- Chicago Transit Authority (CTA)
- Metropolitan Dade County (Metrorail – under construction)
- Massachusetts Bay Transportation Authority (MBTA)
- New York City Transit Authority (NYCTA)
- Port Authority Transit Corporation of Pennsylvania and New Jersey (PATCO)
- Southeastern Pennsylvania Transportation Authority (SEPTA)
- Washington Metropolitan Area Transit Authority (WMATA)

In order to classify the elevated structures in these systems according to their potential noise emission, the following structure components were considered:

- Stringer (longitudinal girder)
- Structure Deck
- Track Support
- Rails
- Noise Barrier.

Accordingly, 17 different structure categories were identified; this number is reduced to 13 categories if consideration of noise barriers is excluded from the classification scheme.

Noise levels, in terms of the A-weighted maximum level (L_{max}) and single event noise exposure level (SENEL) descriptors, were estimated for each type of elevated structure on the basis of field measurements and/or published data. These results, together with train schedule information were used to estimate the day-night average sound levels (L_{dn}) in the wayside community due to transit operation. The transit L_{dn} values were compared with ambient L_{dn} estimates in order to define the areas of transit noise influence. Population data were then applied so as to estimate the number of people exposed to various levels of transit noise and to evaluate the Sound Level Weighted Population (LWP) — a measure of noise impact that takes into account the number of people exposed to transit noise, together with the magnitude of the noise exposure.

It was found that approximately 384,000 people at residential locations in the U.S. are exposed to noise from rail transit operations on elevated structures. Figure ES-1 shows the distribution of wayside residential noise exposure, indicating that about 40 percent of the total impacted population is exposed to transit

noise L_{dn} levels in the 80 to 85 dB range. The total LWP was determined to be approximately 646,000, corresponding to an average transit L_{dn} of 82.5 dB experienced by the impacted population, and implying that the nationwide noise impact from elevated transit structures is equivalent to about 646,000 people being 100 percent impacted.

The inventory results indicate that the structure types may be aggregated into three general categories; these and their rank-ordering in terms of L_{max} and LWP are shown in Table ES-1. The noisiest structures - open deck (wood tie) on steel girders carrying jointed rail - are also the most numerous and account for about 91 percent of the total nationwide noise impact. Structures with concrete or concrete/steel composite decks, ballasted track and jointed rail are somewhat less noisy and account for about 8 percent of the total noise impact. Structures where welded rail is resiliently fastened to concrete decks tend to be relatively quiet; although these structures make up about one third of all U.S. elevated structures, they account for only about 1 percent of the total noise impact.

TABLE ES-1. WAYSIDE NOISE IMPACT OF GENERAL CATEGORIES OF U.S. RAIL TRANSIT ELEVATED STRUCTURES

Structure Description	Route Distance km (miles)	Range of L_{max} at 60 km/h (37 mph), 7.5 m (25 ft), in dBA	Residential Noise Impact (LWP)
Steel girders, open deck (wood tie), jointed rail	143.5 (89.2)	100-107	585,643
Steel and/or concrete girders, concrete or concrete/steel deck, ballast and wood tie, jointed rail	24.8 (15.4)	95-99	51,031
with noise barrier	3.2 (2.0)	88-92	2,593
Steel or concrete girders, concrete deck, resilient track fasteners, welded rail	62.6 (38.9)	76-91	6,210
with noise barrier	18.8 (11.7)	70-76	529
with nonresilient fasteners	0.3 (0.2)	93-101	30
TOTAL	253.0 (157.0)	70-107	646,036

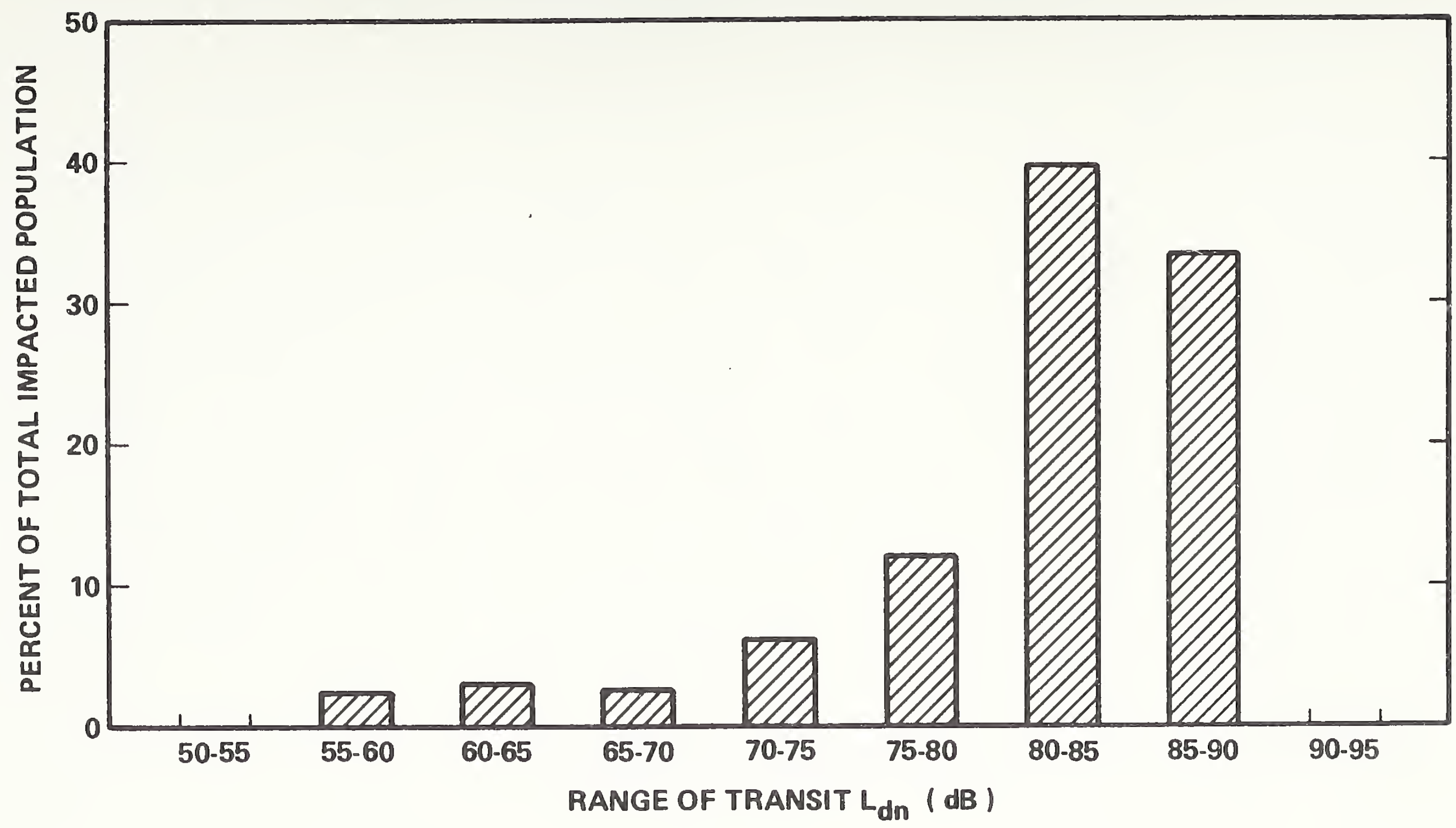

FIGURE ES-1. DISTRIBUTION OF NOISE EXPOSURE FOR THE WAYSIDE RESIDENTIAL POPULATION NEAR U.S. ELEVATED RAIL TRANSIT STRUCTURES

1. INTRODUCTION

Urban rail rapid transit operation on elevated structures is a source of significant noise impact on large segments of the populations of major cities of the United States, as in other parts of the world. Wayside A-weighted sound levels for trains running on elevated structures can be higher by as much as 20 dB than corresponding levels for at-grade operation [*1*], partially due to sound radiation from the vibrating components of the elevated structures. In view of the large number of people who live and work near major transit routes, and who thus are exposed to these high noise levels, it is evident that elevated rail transit structure noise is a significant environmental problem.

In order for a given amount of elevated structure noise control effort to result in the greatest benefit, such effort should be directed so as to achieve the greatest reduction in the overall noise impact. For this purpose there exists a need for an inventory of elevated transit structures, together with development of a rank-ordering of the various structure types in terms of their noise impact. This report provides such an inventory for all U.S. urban rail rapid transit systems.

It thus is the purpose of this report to (1) identify and describe existing and planned elevated rapid transit structures in the U.S., (2) classify the various types of structures in terms of their noise-related characteristics, and (3) evaluate and rank-order the noise levels and noise impact for each structure type. Section 2 of this report discusses the approach and methodology used here to assess the noise impact of elevated structures. Section 3 describes the identification and classification of U.S. elevated rapid transit structures. Section 4

provides an overview of the nationwide inventory and noise impact. Detailed inventory and noise impact results for individual U.S. rapid transit systems are included in appendices; these appendices are presented so that they may be read by themselves without reference to the rest of the report, and therefore include intentional repetitions of some information. Supplementary information on noise models, measurements, and assessment data is also included in appendices.

2. APPROACH AND METHODOLOGY

2.1 Definitions of Noise Descriptors

Sound (or Noise) Level: The terms "sound level" and "noise level" are used interchangeably in this report to refer to the overall A-weighted sound pressure level, given in terms of A-weighted decibels (dBA). The decibel scale is a logarithmic scale used to measure the relative noisiness of sounds; a 10 dB increase in sound level corresponds to a subjective doubling of loudness. A-weighting weights the various frequency components of a sound level in accordance with the sensitivity of human hearing.

Maximum A-Weighted Sound Level, L_{max}: L_{max}, as used in this report, refers to the greatest sound level that is experienced at a given location during the passby of a rail transit vehicle on an elevated structure. L_{max} is also expressed in dBA. The top portion of Fig. 2-1 shows a typical time-history trace of wayside noise level for a transit vehicle passby on elevated structure and indicates the definition of L_{max}.

Single Event Noise Exposure Level, SENEL: The SENEL, as used in this report, is defined as the sound level of a signal with a duration of one second that contains the same acoustic energy as the time-integrated sound level of a single train passby. SENEL, which is expressed in dBA, provides a measure which accounts for both the duration and the level of a single noise event. For example, the area under the time-history curve in Fig. 2-1 represents the total amount of sound energy arriving at a given receiver location due to a single train passby; the SENEL for this event is the steady sound level occurring over a

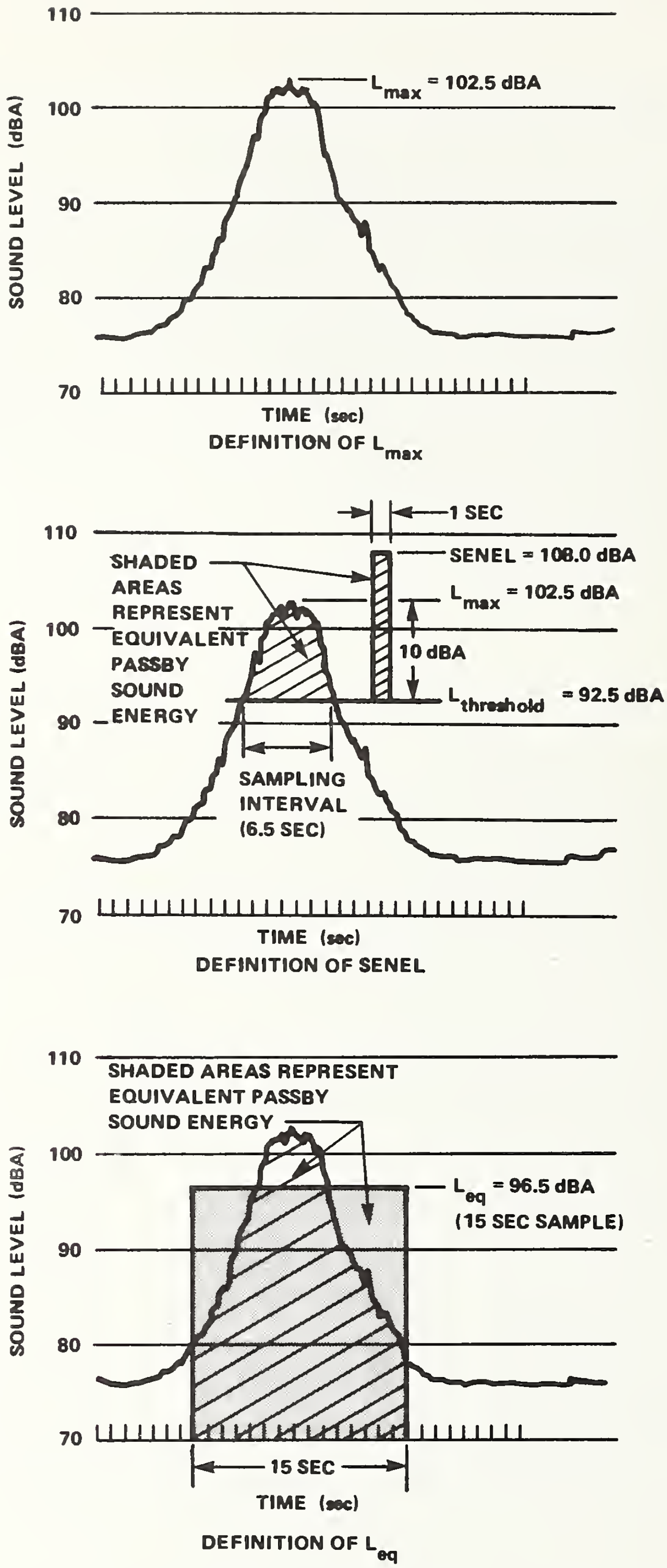

FIGURE 2-1. DEFINITION OF TRAIN PASSBY NOISE DESCRIPTORS

one-second period which corresponds to this same total sound energy. For practical purposes, the level that is 10 dB below the maximum level ($L_{threshold}$) is used to determine the sampling interval for measurement of SENEL, since lower sound levels do not contribute significantly to the total energy. The middle part of Fig. 2-1 illustrates the foregoing concepts.

An approximation to SENEL that is sometimes applied to urban rail transit vehicle noise is L_R, which has been suggested by Schultz [2] and is defined as*

$$L_R = L_{max} + 10 \log T_5, \text{ dBA} ,$$

where L_{max} is the maximum sound level during passby (in dBA) and T_5 is the time interval (in seconds) between points at which the sound level is 5 dB below L_{max}.

Equivalent Sound Level, L_{eq}: The L_{eq} is defined as the energy-average sound level, for a specified averaging time. L_{eq} is the level of a steady-state sound that has the same amount of total energy as the actual fluctuating sound (see bottom part of Fig. 2-1). A typical time period used for the evaluation of L_{eq} is one hour; the hourly-equivalent sound level is denoted by L_{eq}(hr), in dBA. The L_{eq} descriptor may be used in reference to noise from a particular source, such as transit vehicle passbys or from a multitude of sources (e.g., ambient noise).

Day-Night Equivalent Sound Level, L_{dn}: The L_{dn} is used to characterize the energy average sound level in residential areas over a 24-hr period. L_{dn}, expressed in dB, is computed like

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*All logarithms in this report are base 10.

L_{eq}, except that 10 dB is added to the nighttime sound levels (10 p.m. to 7 a.m.). As with L_{eq}, L_{dn} may be used to describe noise from a particular source or from a combination of sources. The term *transit* L_{dn} is used in this report to describe the average day-night sound levels at a given wayside location due only to transit vehicle passbys on elevated structures. The term *ambient* L_{dn} is used in this report to describe the L_{dn} at a community location due to all sources *excluding* transit vehicle passbys.

Another term sometimes used to describe long-term community sound levels is the *daytime equivalent sound level,* L_d. This is defined as the L_{eq} for the daytime period (7 a.m. to 10 p.m.), and represents the daytime component of the L_{dn}.

2.2 Noise Emission Characteristics of Rail Transit Vehicles on Elevated Structures

The primary sources of noise for most rail rapid transit systems are wheel-rail interaction and the vehicle propulsion system. Noise from other sources, such as vehicle auxiliaries and power pickup, is generally of a lower order of magnitude.

Which noise source predominates generally depends on vehicle speed. Auxiliary equipment noise predominates for vehicles at rest or at very low speeds; wheel-rail interaction predominates at mid-range speeds, usually up to 80 km/h (50 mph) or more; and propulsion system noise tends to predominate at higher speeds. In the U.S., most transit vehicle operations on elevated structures occur at mid-range speeds, so that wheel-rail interaction is likely to be the dominant noise source for most of the elevated rail systems surveyed in this report.

Wheel-rail interaction noise originates from wheel and rail roughness during rolling contact, as well as from impacts due to wheel flats and rail discontinuities (e.g. rail joints and switches). In addition, wheel "squeal" may be generated by the sliding of wheels on the rail, which typically occurs around curves. Wheel-rail noise is radiated from the wheels and rail to the wayside community by direct airborne paths. Furthermore, wheel-rail vibration may be transmitted to the car body and elevated structures, and these may radiate additional noise.

Wayside sound levels near elevated transit structures are a function of train speed, train length, distance from the track, shielding, air and ground attenuation, structure type and vehicle and track condition. The effects of these parameters are discussed below.

Train Speed. Measurements of A-weighted sound levels for a variety of rail vehicles on both jointed and welded rail indicate that L_{max} varies as 30 log (speed) [*3*]. This typical speed dependence implies an L_{max} increase of 9 dB per doubling of speed. The sound level integration of a transit vehicle passby over time (see Appendix A) suggests that if L_{max} varies as 30 log (speed), then the SENEL varies as 20 log (speed). This implies that SENEL increases by 6 dB per doubling of speed, if all other conditions are constant. These typical 30 log (speed) and 20 log (speed) relationships are used in this report for speed normalization of L_{max} and SENEL data, respectively, unless specific information is available to indicate that other relations apply.

Train Length. The relationship between train length and L_{max} depends on the distance of the observer from the track. Close to the track, the L_{max} is dominated by noise from the nearest car, and thus the effect of train length is negligible.

The effect of train length becomes more pronounced at greater distances. Since the data in this report is normalized to a standard distance of 7.5 m (25 ft), and since train lengths typically vary between 2 and 11 car lengths, the corrections for train length are not significant (i.e., they amount to 1 dB or less). Thus, no train-length adjustment is applied to L_{max} data for the purposes of the noise impact analysis of this report. However, the usual energy-related adjustment for 10 log (number of cars) is applied for normalization of SENEL data.

Distance. Sound level attenuation with distance for rail cars depends on the average wheel-truck spacing and total train length. Rathe [*4*] suggests estimating sound level attenuation corresponding to a line source with dipole directivity, as shown in Fig. 2-2. At distances that are less than about 2/3 of the wheel-truck spacing or greater than about 2/3 of the train length, the L_{max} varies as 20 log (distance), as for a point noise source. Between these two distances, L_{max} varies as 10 log (distance), as for an ideal line source.

The L_{max} data in this report are typically normalized to 7.5 m (25 ft) from distances ranging between 3.75 m (12.5 ft) and 30 m (100 ft). In view of the above model and typical train geometry, the normalization of L_{max} data is here accomplished using the 20 log (distance) relation for data observed at distances of less than 7.5 m (25 ft) and using an adjustment of 10 log (distance) for data from distances between 7.5 m (25 ft) and 30 m (100 ft). For total energy-type descriptors, such as SENEL and L_{dn}, acoustic line source attenuation variation as 10 log (distance) is used.

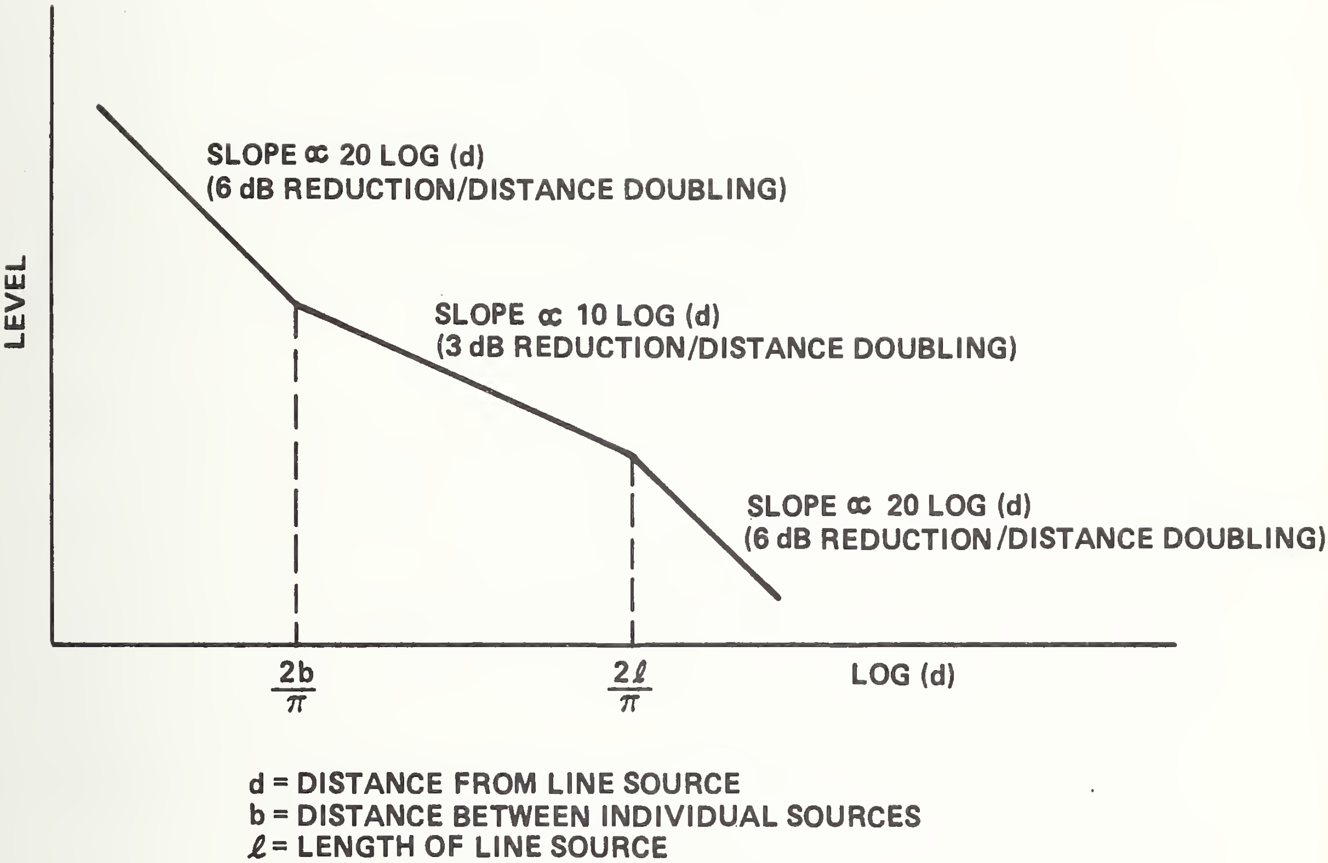

FIGURE 2-2. SOUND PRESSURE LEVEL ATTENUATION WITH DISTANCE FOR A FINITE STRAIGHT-LINE SOURCE CONSISTING OF A ROW OF INDIVIDUAL DIRECTIONAL (DIPOLE) SOURCES (AFTER RATHE [4])

Shielding. Attenuation of elevated transit noise may result from shielding by intervening structures. For densely built-up areas, with tall, continuous buildings on both sides of an elevated structure, Schultz [5] points out that noise impact may be limited to the first row of buildings. The shielding effect of building rows, however, diminishes with decreasing building density. Components of an elevated structure, such as beam webs, may also act to provide noise-shielding of some train components. Such shielding effects are considered in this inventory on an appropriate case-by-case basis.

Air and Ground Attenuation. Excess noise attenuation, beyond that due to the spreading of sound with increasing distance from the structure, may occur due to air and ground effects. However, these effects are not likely to be significant within the practical limits of this analysis and therefore are neglected here.

Structure Type. The physical characteristics of elevated structures control the transmission of vibration from the wheel-rail interface to the various structural members, and the radiation of noise from these components. The components that can significantly affect elevated structure noise serve as a basis for the classification of structures as described in Sec. 3 of this report.

Vehicle and Track Condition. The conditions of transit vehicle trucks, propulsion systems, and wheels and the condition of the track can affect noise levels along elevated transit routes. However, detailed information on vehicle or track condition and resultant noise effects is not generally available. Therefore, the noise estimation and impact analyses in this report are

based on data from a variety of typical vehicles in revenue service at a variety of track locations, where possible, and otherwise on whatever data are available.

2.3 Noise Estimation Methodology

The estimation of noise from elevated transit structures was accomplished on the basis of data in the general literature, where available. For those transit system analyses requiring additional data, field measurements were conducted, as described below.

2.3.1 Noise measurement and data analysis

Noise measurements of transit system operations on elevated structures were conducted at three transit systems, specifically for this project: the Chicago Transit Authority (CTA), Massachusetts Bay Transportation Authority (MBTA), and New York City Transit Authority (NYCTA) systems. Although procedures varied slightly depending on location, the general measurement methodology is described below.

Noise measurements were performed at locations representative of each type of elevated structure and at community environments judged appropriate for the particular transit system being surveyed. Measurement sites were chosen between transit stations, so that train speeds were relatively high and constant. The measurement microphone was positioned at approximately rail height and at 7.5 m (25 ft) from the centerline of the nearest track, as suggested by Schultz [5]. The microphone was located a minimum of 1.8 m (6 ft) from any major reflecting surface.

Approximately 12 train passages were monitored at each location, including 6 passbys on the near track and 6 on the far

track. Train speeds were clocked using a stopwatch, and the number and type of cars were noted for each passage. Ambient noise levels were monitored between train passbys. Photographs were taken to document each measurement site.

A BBN Model 614 Portable Noise Monitor was used to sample ambient noise levels and train passby noise levels. This unit consists of an ANSI Type 1 sound level meter, combined with a system that automatically samples the A-weighted sound level 8 times per second and calculates and prints out statistical or single event data. The monitor was used in the statistical mode to measure the ambient L_{eq} between train passbys and was used in the single event mode to sample train passages.

Tape recordings were also made for selected train passbys using a Kudelski Nagra IV-SJ tape recorder operating at 7.5 ips. These data were subsequently reduced in the laboratory, as follows. An A-weighting filter and graphic level recorder were used to generate time-history plots for each passby. From these plots, sample intervals were selected that included a dynamic range of at least 10 dB; a spectrum analyzer (General Radio Type 1921) was then used to provide 1/3-octave band sound pressure level spectra for samples of each event.

Field calibration was performed before and after each set of measurements at each location by use of a General Radio Model 1567 Acoustic Calibrator, which provides a single frequency (1000 Hz), single level (114 dB) signal. Figure 2-3 provides a block diagram of the typical noise measurement and analysis instrumentation used in this project.

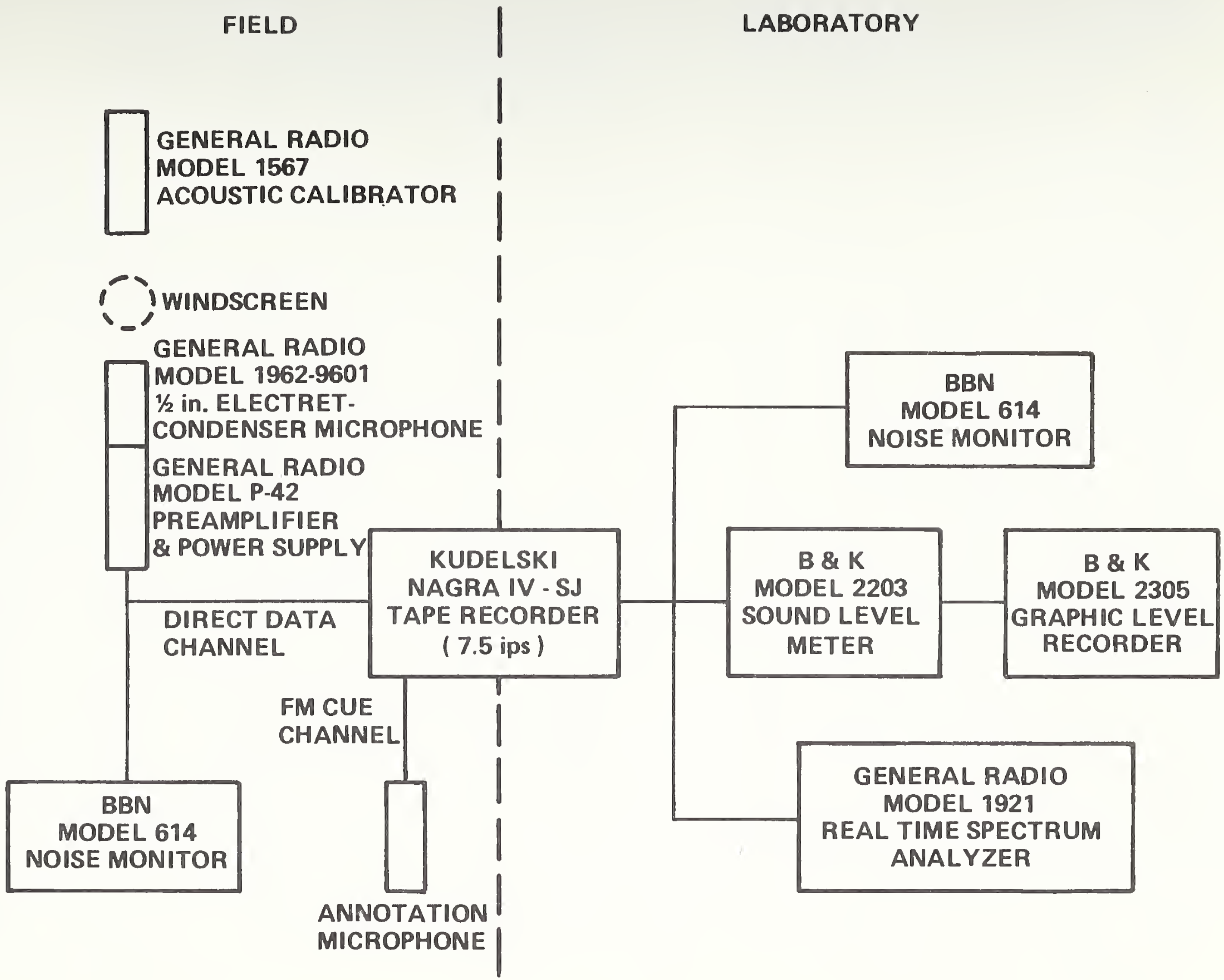

FIGURE 2-3. BLOCK DIAGRAM OF TYPICAL DATA ACQUISITION AND REDUCTION SYSTEM

2.3.2 Calculation of transit L_{dn}

The calculation of transit day-night equivalent sound level (L_{dn}) is based on the SENEL of a "typical" train passby, obtained by normalizing the available data to the average system speed and train length by means of the adjustments described in Section 2.2. The transit L_{dn} may be calculated by summing the sound energy of all train passbys, with 10 dB added to nighttime (10 p.m. to 7 a.m.) data, and by logarithmically averaging the result over a 24-hr period. The transit L_{dn}, thus, can be computed from train passby SENEL and schedule data as follows:

$$L_{dn}(d) = SENEL(d) + 10 \log (N_{day}+10N_{night}) - 49.4 \ , \qquad (2.1)$$

where

$L_{dn}(d)$ = day-night average sound level, in dB, at a distance d,

SENEL(d) = single event noise exposure level, in dBA, for a typical train passby at the same distance d,

N_{day} = number of train passbys between 7 a.m. and 10 p.m.,

N_{night} = number of train passbys between 10 p.m. and 7 a.m.

In the absence of measured SENEL data, SENEL can be estimated from measured L_{max} data using the relation (see Appendix A):

$$SENEL(d) = L_{max}(d) + 10 \log \left(\frac{11.3d}{v}\right) \quad , \qquad (2.2)$$

where

SENEL(d) = single event noise exposure level, in dBA, measured at distance d,

$L_{max}(d)$ = maximum passby noise level, in dBA, measured at distance d,

d = measurement distance from the track centerline, in meters (= distance in ft × 0.3)

v = train speed, in km/h (= speed in mph × 1.6).

L_{dn} is adjusted for distance assuming attenuation variation with 10 log (distance), as discussed previously.

2.4 Fractional Impact Assessment Methodology

The fractional impact evaluation for elevated transit structure noise is accomplished by the method outlined by Schultz [5]. The Fractional Impact Method takes account of the *intensive* (i.e., dependent on the noise level) and *extensive* (i.e., dependent on the size of the affected population) aspects of the situation and yields a single number, the Sound Level Weighted Population (LWP), which quantifies the integrated effect of the noise on the total exposed population. The details of accomplishing this analysis for the various elevated rail systems differ, depending on the particular circumstances and data availability, but the general steps proceed as described below.

1. *Ambient L_{dn} Estimation.* Unless actual measured data are available, the estimation of ambient L_{dn} (without train noise) near an elevated line is generally accomplished using the relation [6]

$$L_{dn} = 10 \log (\rho) + 22 \text{ dB} \quad , \qquad (2.3)$$

where ρ = population density (people per square mile).

This equation is an empirically determined relation developed on the basis of a U.S. Environmental Protection Agency (EPA) study of noise levels vs population density in the United States.

2. *Transit L_{dn} Estimation.* The transit L_{dn} component is estimated for typical train operation by the methods described in Section 2.3. Site-specific conditions, such as wheel squeal, are neglected for the purposes of this broad assessment. A "transit corridor" is determined that includes all areas where the transit L_{dn} is above a value that is 5 dB below the ambient L_{dn}. In densely built-up areas (e.g., Chicago, New York, Philadelphia), the transit corridor is limited to the first row of buildings along the elevated transit structure. For less densely built-up areas, distance and shielding attenuation are included in consideration of the limits of the transit corridor.

3. *Population Inventory.* The population within the transit corridor is estimated from actual physical inventories, from population density data, or from a count of residences (assuming an average of three people per residential unit). Where appropriate, this population is reduced by one-half to account for the assumption that only half of the people

(i.e., those in rooms that face the tracks) are significantly impacted.* The resultant number of people within the transit corridor is defined as the "impacted population." For areas with heavy commercial activity near the elevated structures, the impacted population is broken down into "commercial plus residential" and "residential only" categories. Impacted population is then tabulated with respect to transit L_{dn} exposure for each station-to-station segment along each elevated line.

4. *LWP Calculation.* The Sound Level Weighted Population (LWP) for each segment between elevated line stations is calculated by multiplying the impacted population by the noise weighting function (W) corresponding to the transit L_{dn} at each residential/commercial location. The weighting functions $W(L_{dn})$ are listed in Table 2-1.* The total LWP is then calculated for each elevated line, system, and structural type by summing the LWP values for the appropriate line segments.

A flow chart summarizing the noise impact assessment methodology for elevated rapid transit structures is provided in Fig. 2-4.

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*The suggested halving of the affected population and the weighting function are based on the documented reaction of populations living in noise-impacted environments. The weighting function values are derived from social survey data relating the fraction of the sample population expressing a high degree of annoyance to values of day-night average sound level (see Ref. 5).

TABLE 2-1. WEIGHTING FUNCTION $W(L_{dn})$

L_{dn}	$W(L_{dn})$	L_{dn}	$W(L_{dn})$	L_{dn}	$W(L_{dn})$
35.0	0.006	57.0	0.162	79.0	1.384
35.5	0.006	57.5	0.173	79.5	1.380
36.0	0.007	58.0	0.184	80.0	1.428
36.5	0.007	58.5	0.196	80.5	1.476
37.0	0.008	59.0	0.208	81.0	1.526
37.5	0.009	59.5	0.221	81.5	1.577
38.0	0.009	60.0	0.235	82.0	1.628
38.5	0.010	60.5	0.250	82.5	1.682
39.0	0.011	61.0	0.265	83.0	1.736
39.5	0.012	61.5	0.281	83.5	1.791
40.0	0.013	62.0	0.297	84.0	1.848
40.5	0.014	62.5	0.314	84.5	1.907
41.0	0.015	63.0	0.332	85.0	1.966
41.5	0.017	63.5	0.351	85.5	2.027
42.0	0.018	64.0	0.371	86.0	2.090
42.5	0.019	64.5	0.391	86.5	2.154
43.0	0.021	65.0	0.412	87.0	2.219
43.5	0.023	65.5	0.433	87.5	2.286
44.0	0.025	66.0	0.456	88.0	2.355
44.5	0.027	66.5	0.479	88.5	2.425
45.0	0.029	67.0	0.503	89.0	2.497
45.5	0.031	67.5	0.528	89.5	2.571
46.0	0.034	68.0	0.554	90.0	2.647
46.5	0.036	68.5	0.580	90.5	2.724
47.0	0.039	69.0	0.607	91.0	2.804
47.5	0.042	69.5	0.636	91.5	2.885
48.0	0.046	70.0	0.664	92.0	2.968
48.5	0.049	70.5	0.694	92.5	3.054
49.0	0.053	71.0	0.725	93.0	3.141
49.5	0.057	71.5	0.756	93.5	3.231
50.0	0.061	72.0	0.788	94.0	3.323
50.5	0.066	72.5	0.822	94.5	3.418
51.0	0.071	73.0	0.855	95.0	3.514
51.5	0.076	73.5	0.890	95.5	3.614
52.0	0.082	74.0	0.926	96.0	3.715
52.5	0.088	74.5	0.963	96.5	3.820
53.0	0.094	75.0	1.000	97.0	3.927
53.5	0.101	75.5	1.039	97.5	4.036
54.0	0.108	76.0	1.078	98.0	4.149
54.5	0.166	76.5	1.118	98.5	4.264
55.0	0.124	77.0	1.159	99.0	4.388
55.5	0.133	77.5	1.202	99.5	4.504
56.0	0.142	78.0	1.245	100.0	4.629
56.5	0.152	78.5	1.289	100.5	4.757

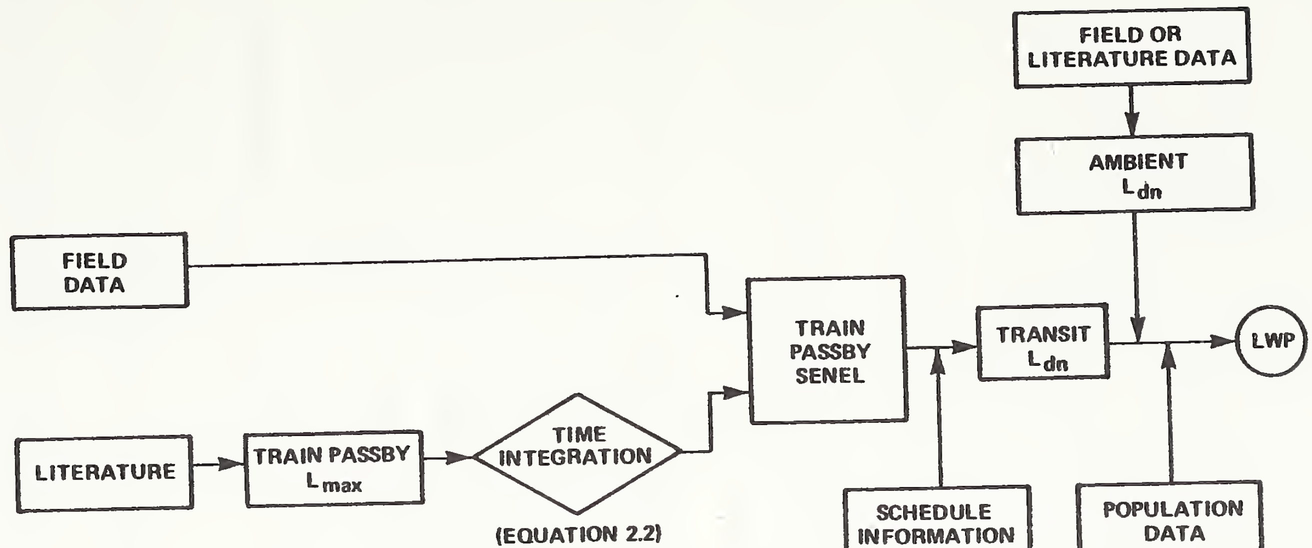

FIGURE 2-4. FLOW CHART OF GENERAL NOISE IMPACT ASSESSMENT METHODOLOGY FOR ELEVATED TRANSIT STRUCTURES

3. IDENTIFICATION AND CLASSIFICATION OF ELEVATED STRUCTURES

The general term *elevated structure* includes both rail-transit elevated guideways and railroad bridges. Railroad bridges typically consist of relatively long segments spanning rivers or of relatively short segments spanning roadways. In either case, the number of people affected by noise from such bridges is small compared with the number of people living adjacent to rail transit elevated guideways. Therefore, the inventory provided in this report is limited to rail-transit elevated guideways. Also, embankments are not considered as elevated transit structures for the present purpose.

This report includes inventories of elevated structures in nine U.S. urban rail transit systems, listed below and alphabetized according to the area name:

- Metropolitan Atlanta Rapid Transit Authority System (MARTA)
- Bay Area Rapid Transit System (BART)
- Chicago Transit Authority Rail Rapid Transit System (CTA)
- Metropolitan Dade County Rapid Transit System (Metrorail)
- Massachusetts Bay Transportation Authority System (MBTA)
- New York City Transit Authority System (NYCTA)
- Port Authority Transit Corporation of Pennsylvania and New Jersey (PATCO)
- Southeastern Pennsylvania Transportation Authority Rail Transit System (SEPTA)
- Washington Metropolitan Area Transit Authority System (WMATA).

All of the above systems, with the exception of the Dade County Metrorail, are currently in operation. Metrorail is included here because its design is far enough advanced to permit one to derive meaningful impact estimates. The Greater Cleveland Regional Transit Authority System (RTA), the Port Authority Trans-Hudson Corporation System (PATH), and the Staten Island Rapid Transit Operating Authority System (SIRT) are not included in this assessment inventory, because in these systems there are no elevated guideways as defined in this report.

The system developed for the classification of elevated structures is based on consideration of those structural components that are likely to be significant in terms of noise and vibration transmission and radiation. These components are: the stringer (longitudinal support girder), the deck, the rail supports, and the track (rail) itself. The presence or absence of a noise barrier for shielding the wheel/rail area is an additional consideration (although such shielding components affect the noise significantly only if noise due to structural vibrations is not greatly predominant). The structure support columns, lateral girders, and bents are not considered acoustically significant, and therefore are not considered in the classification scheme.

The classification categories used to describe U.S. urban rail transit system elevated structures are as follows:

1. *Stringer (Longitudinal Girder) Type*

    a. steel solid web girder

    b. steel lattice web girder

    c. steel box girder

d. concrete beam girder

e. concrete box girder

f. composite steel/concrete girder.

2. *Structure Deck Type*

   a. open deck (wood ties)

   b. concrete slab

   c. composite concrete and steel.

3. *Track Support Type*

   a. direct fixation

   b. ballast and wood ties

   c. resilient rail fasteners.

4. *Track Type*

   a. jointed rail

   b. welded rail.

5. *Noise Barrier*

   a. yes

   b. no.

Table 3-1 identifies the various types of elevated structures present in each U.S. rail transit system, along with approximate route distances for each.

TABLE 3-1. U.S. URBAN RAIL TRANSIT SYSTEM ELEVATED STRUCTURES

Transit System	Elevated Structure Classification					Route Distance km(mi)
	Stringer Type	Deck Type	Track Support Type	Track Type	Noise Barrier	
MARTA	Steel box girder	Concrete slab	Resilient fasteners	Welded	Yes	1.3(0.8)
	Steel box girder	Concrete slab	Resilient fasteners	Welded	No	0.9(0.6)
	Concrete box girder	Concrete slab	Resilient fasteners	Welded	Yes	0.6(0.4)
BART	Concrete box girder	Concrete slab	Resilient fasteners	Welded	No	32(20)
CTA	Steel solid web girder	Open (wood ties)	Direct fixation	Jointed	No	43(27)
	Steel lattice web girder	Open (wood ties)	Direct fixation	Jointed	No	7.2(4.5)
	Steel solid web girder	Concrete slab	Ballast and wood ties	Jointed	Yes	1.6(1.0)
Dade County Metrorail	Concrete beam girder	Concrete slab	Resilient fasteners	Welded	Yes	34(21)
	Concrete beam girder	Concrete slab	Resilient fasteners	Welded	No	
MBTA	Steel solid web girder	Concrete slab	Ballast and wood ties	Jointed	No	1.6(1.0)
	Steel solid web girder	Concrete slab	Direct fixation	Welded	No	0.3(0.2)
	Steel solid web girder	Open (wood ties)	Direct fixation	Jointed	No	3.7(2.3)
	Steel lattice web girder	Open (wood ties)	Direct fixation	Jointed	No	3.4(2.1)
NYCTA	Steel solid web girder	Open (wood ties)	Direct fixation	Jointed	No	84.5(52.5)
	Steel lattice web girder	Open (wood ties)	Direct fixation	Jointed	No	0.8(0.5)
	Concrete beam girder	Concrete slab	Ballast and wood ties	Jointed	No	8.9(5.5)
	Steel and concrete girder	Steel/concrete composite	Ballast and wood ties	Jointed	Yes	1.6(1.0)
PATCO	Concrete beam girder	Concrete slab	Resilient fasteners	Welded	No	1.4(0.9)
SEPTA	Steel lattice web girder	Steel/concrete composite	Ballast and wood ties	Jointed	No	3.9(2.4)
	Steel lattice web girder	Concrete slab	Ballast and wood ties	Jointed	No	8.5(5.3)
	Steel lattice web girder	Open (wood ties)	Direct fixation	Jointed	No	0.4(0.3)
	Concrete beam	Concrete slab	Resilient fasteners	Welded	No	0.8(0.5)
WMATA	Steel solid web girder	Concrete slab	Resilient fasteners	Welded	No	1.6(1.0)
	Steel box girder	Concrete slab	Resilient fasteners	Welded	No	8.0(5.0)
	Concrete box girder	Concrete slab	Ballast and wood ties	Welded	No	2.0(1.2)
	Concrete box girder	Concrete slab	Resilient fasteners	Welded	No	0.6(0.4)

4. SUMMARY AND CONCLUSIONS

A comprehensive summary of the U.S. elevated rail transit structure noise impact inventory is provided in Table 4-1. This table lists 17 different types of elevated structures found in nine U.S. transit systems, with a total route distance of approximately 253 km (157 miles). Noise level and noise impact data are provided for each structure classification; these results are obtained from noise impact studies of the individual transit systems (see Appendices B through J), supplemented by data from references as noted. Table 4-2 provides the distribution of transit noise exposure for the wayside residential population near each transit system surveyed in this report.

4.1 Noise Levels

The noise level estimates provided in Table 4.1 are based on field measurements and data in the literature. L_{max} data are estimated for a train passby at 60 km/h (37 mph) measured at rail height, 7.5 m (25 ft) from the track centerline, using the normalization methodology discussed in Section 2-2. Nonstructure noise levels are included where available; these levels are normalized estimates for train passbys at grade, on ballasted track.

A review of the noise estimates suggests three general categories of elevated structures, rank-ordered according to L_{max} as follows:

1. Steel girders, open deck (wood tie), jointed rail: L_{max} = 100 to 107 dBA,

2. Steel and/or concrete girders, concrete or concrete/steel deck, ballast and wood tie, jointed rail: L_{max} = 95 to 99 dBA (without barrier),

TABLE 4-1. U.S. ELEVATED RAIL TRANSIT STRUCTURE NOISE IMPACT INVENTORY SUMMARY

Elevated Rapid Transit Structure Classification: Stringer Type						Deck Type			Track Support Type			Track Type		Noise Barrier				Estimated Noise Level*		Residential Noise Impact	
																		L_{max} at 7.5 m (25 ft), 60 km/h (37 mph), dBA			
Steel Solid Web Girder	Steel Lattice Web Girder	Steel Box Girder	Concrete Beam Girder	Concrete Box Girder	Steel/Concrete Beam Girder	Open (Wood Tie)	Concrete Slab	Concrete & Steel	Direct Fixation	Ballast & Wood Tie	Resilient Fasteners	Jointed Rail	Welded Rail	Yes	No	Transit System	Route Distance km (mi)	Structure	Nonstructure	Impacted Population (P)	Sound Level Weighted Population (LWP)
X						X			X			X			X	CTA	43 (27)	100	91 [7]	71,852	119,786
																MBTA	3.7 (2.3)	104	98 [8]	1,302	855
																NYCTA	84.5(52.5)	106	90 [9]	225,568	454,245
TOTAL STRUCTURE																	131.2(81.8)			298,722	574,886
X							X		X				X		X	MBTA	0.3(0.2)	97	88 [8]	60	30
X							X			X		X		X		CTA	1.6(1)	90	91 [7]	364	244
X							X			X		X			X	MBTA	1.6(1)	99	98 [8]	296	125
X							X				X		X		X	WMATA	1.6(1)	77	--	0	0
	X					X			X			X			X	CTA	7.2 (4.5)	103	91 [7]	5,672	9,504
																MBTA	3.4 (2.1)	107	98 [8]	412	310
																NYCTA	0.8 (0.5)	101	90 [9]	711	943
																SEPTA	0.4 (0.3)	---	---	0	0
TOTAL STRUCTURE																	11.8 (7.4)			6,795	10,757
	X						X			X		X			X	SEPTA	8.5 (5.3)	96 [10]	---	16,752	22,122
	X							X		X		X			X	SEPTA	3.9 (2.4)	96 [10]	---	10,018	10,087
		X					X				X		X	X		MARTA	1.3 (0.8)	76	---	14	1
		X					X				X		X		X	MARTA	0.9 (0.6)	85	---	33	4
																WMATA	8.0 (5)	77	---	0	0
TOTAL STRUCTURE																	8.9 (5.6)			33	4
			X				X			X		X			X	NYCTA	8.9 (5.5)	95	90 [9]	23,229	18,697
			X				X				X		X	X		Dade Metrorail	17 (10.5)	70	75	2,891	525
			X				X				X		X		X	Dade Metrorail	17 (10.5)	80	75	2,891	525
																PATCO	1.4 (0.9)	90 [11]	83 [11]	392	147
																SEPTA	0.8 (0.5)	91 [10]	---	980	931
TOTAL STRUCTURE																	19.2(11.9)			4,263	1,603
				X			X			X			X		X	WMATA	2.0 (1.2)	77	---	0	0
				X			X				X		X	X		MARTA	0.6 (0.4)	76	---	30	3
				X			X				X		X		X	BART	32 (20)	85 [12]	80 [12,13]	17,712	4,603
																WMATA	0.6 (0.4)	77	---	0	0
TOTAL STRUCTURE																	32.6(20.4)			17,712	4,603
					X			X		X		X		X		NYCTA	1.6 (1.0)	90	90 [9]	3,114	2,349
TOTAL U.S. ELEVATED STRUCTURE																	253 (157)			384,293	646,036

*Unless otherwise referenced, the L_{max} values are estimated from data presented on the appropriate report appendix, using the adjustment techniques presented in Sec. 2.2. Bracketed values refer to references for measured data not discussed in the Appendices.

TABLE 4-2. DISTRIBUTION OF NOISE EXPOSURE FOR THE WAYSIDE RESIDENTIAL POPULATION NEAR U.S. ELEVATED RAIL TRANSIT STRUCTURES

Transit System	Number of People Exposed to Elevated Transit Structure Noise Within Various Ranges of L_{dn}, in dB									
	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	Total
MARTA	29	48								77
BART		8,850	7,322	1,514	26					17,712
CTA				182	1,900	14,682	46,882	14,242		77,888
DADE METRORAIL		405	3,957	1,294	126					5,782
MBTA			539	694	552	239	46			2,070
NYCTA				6,595	17,001	9,023	105,307	114,314	382	252,622
PATCO		81	208	81	22					392
SEPTA					4,253	22,811	686			27,750
WMATA										0
TOTAL	29	9,384	12,026	10,360	23,880	46,755	152,921	128,556	382	384,293

3. Steel or concrete girders, concrete deck, resilient track fasteners, welded rail: L_{max} = 76 to 91 dBA (without barrier).

The noisiest structures are seen to be the open deck (wood tie) steel variety; girder design (i.e., solid vs lattice web) does not seem to be a significant factor relating to noise from these structures according to the above results. Structures with concrete or concrete/steel composite decks, ballasted track and jointed rail are seen to be less noisy than the open deck steel structures; this may be due to the combined effects of ballast absorption and the reduction of structural radiation. Structures with concrete deck, resilient fasteners and welded rail make up the least noisy group of structures. These structures show a wide variation in noise levels, suggesting that factors other than structural characteristics may be strongly influencing noise emission. For example, results for the PATCO and SEPTA structures in this category reveal L_{max} values of 90 to 91 dBA, significantly above the 76 to 85 dBA range encountered for similar structures in newer transit systems. This may result from the predominance of noise generated by vehicle components (e.g., propulsion system, wheels, etc.) for the transit cars used on the PATCO and SEPTA systems. Note that structures with noise barriers are not included in the present discussion, since barrier effects are site-specific.

The nonstructure data indicate that train operations on elevated structures are 1 to 16 dB noisier than operations at grade on ballasted track for similar vehicle and rail conditions. This increase may be due to a combination of factors such as reduction of ground absorption, loss of undercar ballast absorption, and noise radiation from structure components.

4.2 Noise Impact

Table 4.2 provides residential noise impact information for each elevated structure type in terms of impacted population (P) and Sound Level Weighted Population (LWP). The results estimate that approximately 384,300 people in the U.S. are exposed to noise from rail transit operations on elevated structures. The total LWP is estimated to be about 646,000, which implies that the impacted population of 384,300 is exposed to an average L_{dn} of 82.5 dB. In fact, Table 4.2 indicates that about 40% of the total impacted population is exposed to transit noise within the 80 to 85 dB L_{dn} range. Another interpretation of the LWP is that the nationwide noise impact from elevated structures is approximately equivalent to 646,000 people being 100 percent impacted.

The results shown in Table 4.2 lead to a rank-ordering of structure types according to noise impact. The following five structures account for 99 percent of all U.S. elevated structure noise impact:

1. Steel solid web girder, open deck (wood tie), jointed rail: LWP = 574,886,

2. Steel lattice web girder, concrete deck, ballast and wood tie, jointed rail: LWP = 22,122,

3. Concrete beam girder, concrete deck, ballast and wood tie, jointed rail: LWP = 18,697,

4. Steel lattice web girder, open deck (wood tie), jointed rail: LWP = 10,757,

5. Steel lattice web girder, concrete and steel deck, ballast and wood tie, jointed rail: LWP = 10,087.

These results indicate that steel structures with solid web girders, open deck (wood tie) and jointed rail are responsible for the greatest noise impact by far, accounting for 89 percent of the total nationwide LWP. The approximately 131 km (82 miles) of this structure, which are located primarily in New York and Chicago, make up more than half of all U.S. elevated structures.

The five structures listed above are included among the two noisiest structure categories described in Section 4-1. The least noisy structures, which use welded rail mounted on concrete deck with resilient fasteners, account for approximately 70 km (50 miles), or almost one third of all U.S. elevated structures. These structures, however, are found primarily in newer transit systems and account for only 1 percent of the total noise impact from U.S. elevated rail transit structures.

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APPENDIX A: CALCULATION OF SINGLE EVENT NOISE EXPOSURE LEVEL (SENEL) FROM MAXIMUM PASSBY NOISE LEVEL (L_{max})*

The single event noise exposure level, SENEL, for the period from -T/2 to +T/2 is defined as:

$$\text{SENEL} = 10 \log \left[\frac{1}{T_1} \int_{-T/2}^{+T/2} 10^{L_A(t)/10} \, dt \right] , \qquad \text{(A.1)}$$

where $L_A(t)$ is the instantaneous A-weighted sound level, and T_1 is the reference time interval of one second.

The sound level at a distance d from a track during the passage of a single rail car can be expressed as:

$$L_A(t) = L_{max} + 10 \log \left[\frac{(d)^2}{d^2 + (vt)^2} \right] , \qquad \text{(A.2)}$$

where the time t is taken to be zero when the vehicle is at its closest position (i.e., distance d), L_{max} is the sound level of a single car at distance d, and v is the velocity of the vehicle. (Note that v, d, and t here must be in consistent units.)

The single event noise exposure level, SENEL, due to the passage of a single vehicle in the period T then may be found by substituting Eq. (A.2) into Eq. (A.1) above. If T is much greater than the passage time of the vehicle, this then reduces to:

$$\text{SENEL} = L_{max} + 10 \log \left[\frac{\pi d}{T_1 v} \right] .$$

*Adapted from Ref. A.1.

In metric units, this equation is expressed as:

$$SENEL = L_{max} + 10 \log \left[\frac{11.3\, d}{v} \right] ,$$

where d is the distance to track in meters, and v is the train speed in km/h.

The corresponding equation expressed in English units is:

$$SENEL = L_{max} + 10 \log \left[\frac{2.1\, d}{v} \right] ,$$

where d is the distance to track in feet, and v is the train speed in mph.

REFERENCES – APPENDIX A

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APPENDIX B: MARTA INVENTORY

B.1 Elevated Structure Description

The Metropolitan Atlanta Rapid Transit Authority (MARTA) system includes approximately 2.8 km (1.7 miles) of concrete elevated structure. The typical structure consists of a precast or cast-in-place concrete slab deck supporting both eastbound and westbound tracks (see Fig. B-1), with the slab carried by either a steel or a concrete box beam. All sections with concrete box beams have separate structures for each track. Some sections with steel box beams are provided with a noise-control damping treatment. Other sections include a (nonabsorptive) sound barrier, with a height of 1.5 m (5 ft) above the deck and 1.2 m (4 ft) above the top of the rail with an offset distance of 0.6 m (2 ft). The rails are continuously welded and weigh 57 kg/m (115 lb/yd). Hixson rail fasteners with an advertised static stiffness of 175,000 N/cm (100,000 lb/in.), are used throughout, spaced 76 cm (30 in.) on center.

A list of the lengths of the different types of elevated structures currently in use is provided below:

1. *Precast Deck, Steel Box Girder*

a.	with noise barrier only	0.45 km (0.28 miles)
b.	with sound damping only	0.02 km (0.01 miles)
c.	with barrier and damping	0.77 km (0.48 miles)
d.	without barrier or damping	0.84 km (0.52 miles)
	Total	2.08 km (1.29 miles) .

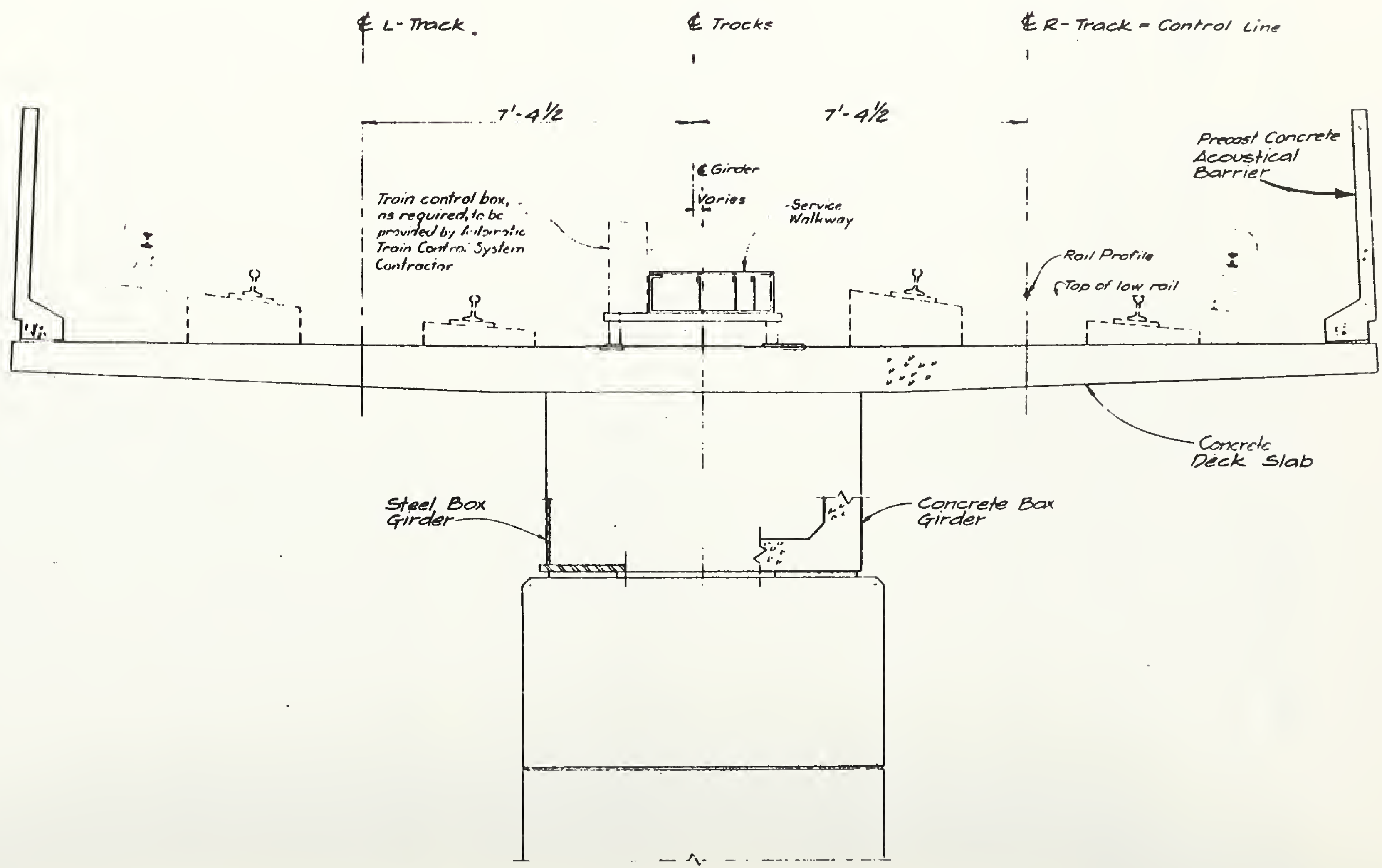


FIGURE B-1. MARTA ELEVATED STRUCTURE TYPICAL SECTION

2. *Cast-In-Place Deck, Steel Box Girder*

a. with noise barrier	0.09 km	(0.05 miles)
b. without noise barrier	0.08 km	(0.05 miles)
Total	0.17 km	(0.10 miles) .

3. *Concrete Deck, Concrete Box Girder*

with noise barrier	0.57 km	(0.35 miles) .
Total Structure	2.82 km	(1.74 miles).

A photograph of a steel box girder MARTA structure (with noise barrier) is provided in Fig. B-2. Figure B-3 is a photograph of a typical section of concrete box girder MARTA structure.

B.2 Noise Estimation

The estimation of L_{dn} for MARTA elevated structures is based on measurements conducted by BBN in April 1979. These measurements were performed using a two-car test train and are described in detail in a memorandum [*B.1*]. The measurements were made near precast deck concrete structure segments with both damped and undamped steel box beams, with and without noise barriers. The measurement results (see Fig. B-4) indicate that the noise reduction due to the barrier is about 9 dB for a train on the track near the barrier at 64 to 97 km/h (40 to 60 mph). Damping seems to reduce noise levels by 1.5 dB or less, depending on speed and test configuration; however, the data are not conclusive. Therefore, the barrier and no barrier results for precast concrete deck structure with undamped steel box beam will be used here for estimation of the noise impact for all

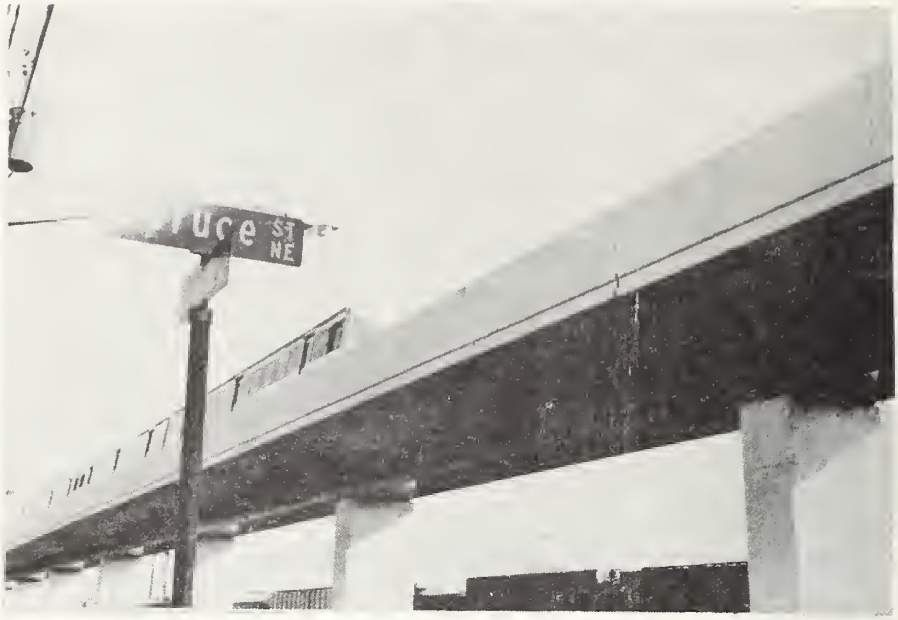


FIGURE B-2. MARTA ELEVATED STRUCTURE WITH STEEL BOX BEAM AND NOISE BARRIER

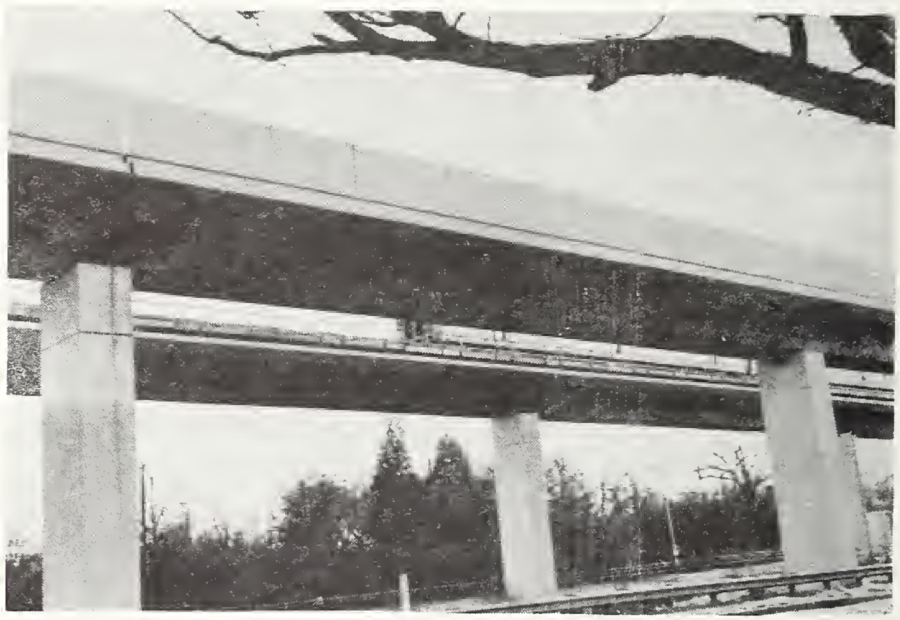


FIGURE B-3. MARTA ELEVATED STRUCTURE WITH CONCRETE BOX GIRDER

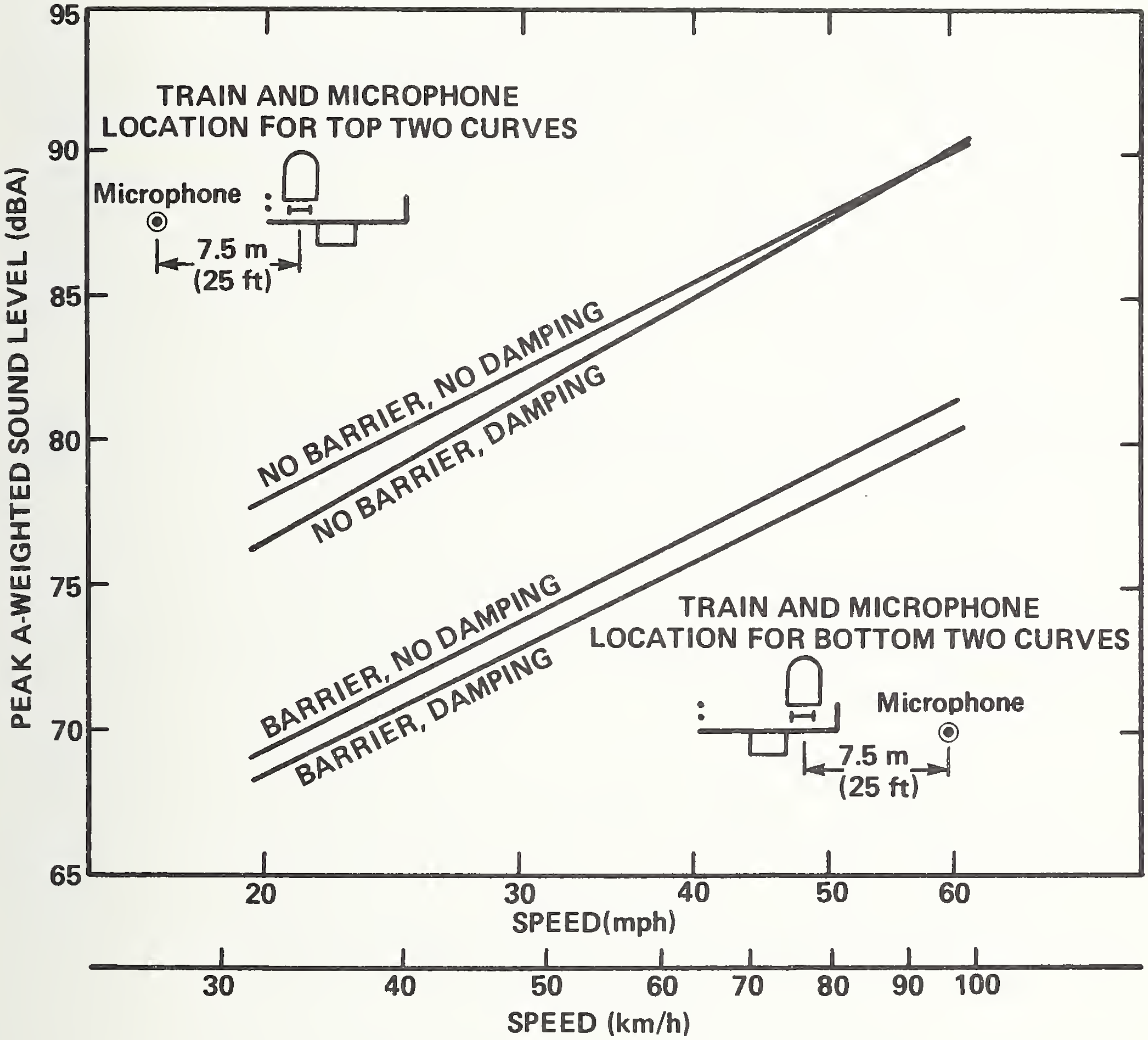


FIGURE B-4. COMPARISON OF EFFECT OF BARRIER AND DAMPING ON PEAK A-WT. SOUND LEVEL [*B.1*]

MARTA elevated structures; since this new system is expected to have minimal noise impact, an in-depth investigation of the noise effects of the various structural types is not warranted at present.

Noise measurement results are listed in Table B-1 in terms of the single event noise exposure level (SENEL) for two-car train passbys on both near and far tracks. Microphones were positioned at deck height, at 7.5 m (25 ft) from the near track centerline, at 12 m (40 ft) from the far track centerline, and at 10 m (32.5 ft) from the structure centerline (see Fig. B-4). Near and far track data were logarithmically averaged and corrected for distance assuming a 10 log (1/distance) variation in order to obtain an average SENEL for two-car train passbys at 30 m (100 ft). An additional 3 dB were added to convert the result to typical four-car trains, assuming that SENEL varies as 10 log (no. of cars). The results are shown in Fig. B.5, which indicates how SENEL varies with speed for structures with and without noise barriers.

The day-night average sound level, L_{dn}, may be calculated by summing the sound energy of all train passbys, with a 10 dB penalty added to nighttime (10 p.m. to 7 a.m.) operations, and averaging the result over a 24-hr period. The L_{dn}, (d) at a distance d, in dBA, may be calculated from:

$$L_{dn}(d) = \text{SENEL}(d) + 10 \log(N_{day} + 10N_{night}) - 49.4 \,, \qquad \text{(B.1)}$$

where SENEL(d) is the single event noise exposure level at a distance d, in dBA. N_{day} is the number of train passbys between 7 a.m. and 10 p.m., and N_{night} is the number of train passbys between 10 p.m. and 7 a.m.

TABLE B-1. MARTA ELEVATED STRUCTURE NOISE MEASUREMENTS* [*B.1*]

Train Speed	SENEL for a Two-Car Test Train (dBA)				ΔSENEL (dBA)	
	Without Barrier		With Barrier		Without Barrier – With Barrier	
	Near Track at 7.5 m (25 ft)	Far Track at 12 m (40 ft)	Near Track at 7.5 m (25 ft)	Far Track at 12 m (40 ft)	Near Track at 7.5 m (25 ft)	Far Track at 12 m (40 ft)
32 km/h (20 mph)	85	--	--	--	--	--
48 km/h (30 mph)	88	--	--	77	--	--
72 km/h (45 mph)	91	86	83	80	8	6
97 km/h (60 mph)	93	--	--	81	--	--

*Precast concrete deck structure with undamped steel box beam.

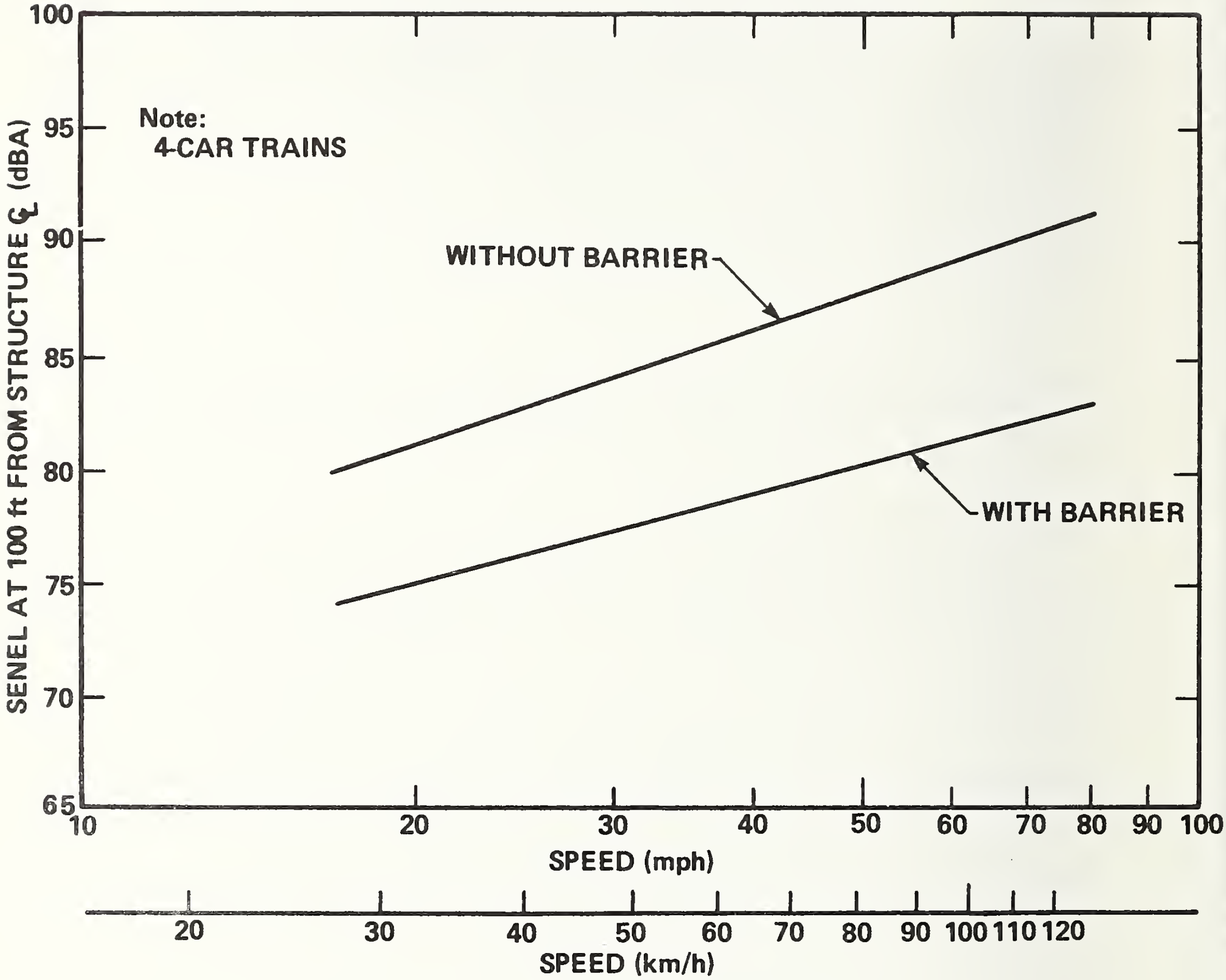


FIGURE B-5. MARTA ELEVATED STRUCTURE NOISE ESTIMATION: SENEL VS SPEED

The MARTA system currently operates 4-car trains at 15-min intervals in each direction between the hours of 5:30 a.m. and 8:00 p.m., with an average speed of 72 km/h (45 mph) on elevated structures [*B.2*]. The SENEL at 30 m (100 ft) for a 4-car train operating at 72 km/h (45 mph), as found from Fig. B-5 is 87 dBA without a noise barrier and 80 dBA with a noise barrier. The schedule data suggest that N_{day} = 104 and N_{night} = 12 (5:30 a.m. to 7:00 a.m.). One thus finds from Eq. (B.1) that the L_{dn} at 30 m (100 ft) is 61 dB without noise barriers and 54 dB with noise barriers. The L_{dn} for distances beyond 30 m (100 ft) is calculated assuming that L_{dn} varies as 10 log (1/distance).

B.3 Fractional Impact Analysis

The fractional impact analysis for the MARTA system elevated structures is accomplished by the method outlined by Schultz [*B.3*], which consists of the steps described below:

1. Ambient noise levels (without MARTA) are estimated using the relation [*B.4*]:

$$L_{dn} = 10 \log (\rho) + 22 \text{ dB} ,$$

where ρ denotes the population density (people per square mile). Based on the 1975 population density of 3,316 people per square mile for the City of Atlanta [*B.5*], the ambient L_{dn} here is estimated to be 57 dB.

2. The transit L_{dn} component is estimated as outlined in the previous section for distances corresponding to residential locations shown on MARTA plan drawings [*B.6*]. Residences at

which the transit L_{dn} is more than 5 dB below the ambient L_{dn} (i.e., less than 52 dB) are not included in the fractional impact analysis.

3. The exposed population is estimated by assuming that there are an average of three people per residential unit. This estimate is reduced by one-half, as suggested by Schultz [*B.3*], because it is expected that only that half of the population that are in rooms facing the tracks are significantly impacted.

4. The Sound Level Weighted Population (LWP) is calculated by multiplying the exposed population by the noise weighting function (W) for the associated transit L_{dn}.

The fractional impact analysis for the MARTA system elevated structures indicates that the noise impact is minimal; the results are summarized below:

	Impacted Population	*LWP*
Steel box girder structure without noise barrier	33	4
Steel box girder structure with noise barrier	14	1
Concrete box girder structure with noise barrier	30	3
Total	77	8.

REFERENCES — APPENDIX B

B.1 Wittig, L.E., "Preliminary Report on Noise and Vibration Measurements on the MARTA Elevated Rapid Transit Structure," BBN Memo to Eric Ungar (11 July 1979).

B.2 Solomon, I.M., private communication (September 1979).

B.3 Schultz, T.J., "Noise Rating Criteria for Elevated Rapid Transit Structures," BBN Report No. 3905 (April 1979).

B.4 U.S. Environmental Protection Agency, "Population Distribution of the United States as a Function of Outdoor Noise Level," Report No. EPA-550/9-74-009A (June 1974).

B.5 U.S. Department of Commerce, Bureau of the Census, "County and City Data Book 1977 — A Statistical Abstract Supplement," (1977).

B.6 MARTA, East Line Plan Drawings (1974-1975).

APPENDIX C: BART INVENTORY

C.1 Elevated Structure Description

The BART system contains approximately 32 km (20 miles) of elevated structure, located as shown on Fig. C-1. The predominant structural design consists of reinforced concrete deck with each trackway supported by a separate trapezoidal concrete girder (see Fig. C-2). About 0.8 km (0.5 miles) of the system consists of a composite steel/concrete structure, where the girder is of steel instead of concrete. The basic track design consists of continuous welded rail, mounted on the concrete deck with resilient rail fasteners. Some short bridge sections have ballasted track; these segments are not included in this impact analysis, because they make no significant contribution.

C.2 Noise Estimation

Noise measurements conducted by Wilson, Ihrig & Associates [*C.1*] indicate an average maximum train passby noise level of 91 dBA at 15 m (50 ft) from BART concrete aerial structures, for trains at speeds of 129 km/h (80 mph), and with an average of 4.5 cars per train. Noise levels observed at a composite steel/concrete structure (Walnut Creek Bridge) were 1 to 4 dB lower than those observed adjacent to all-concrete aerial structures. Since the composite structure accounts for only 10 spans of the system, ranging in length between 30 and 183 m (100 and 600 ft), the noise impact estimate for all BART elevated structures is based on the concrete structure measurements.

For the purposes of the present analysis, train speeds are assumed to average 64 km/h (40 mph) within 610 m (2000 ft) of the stations and 129 km/h (80 mph) elsewhere [*C.2*]. Previous

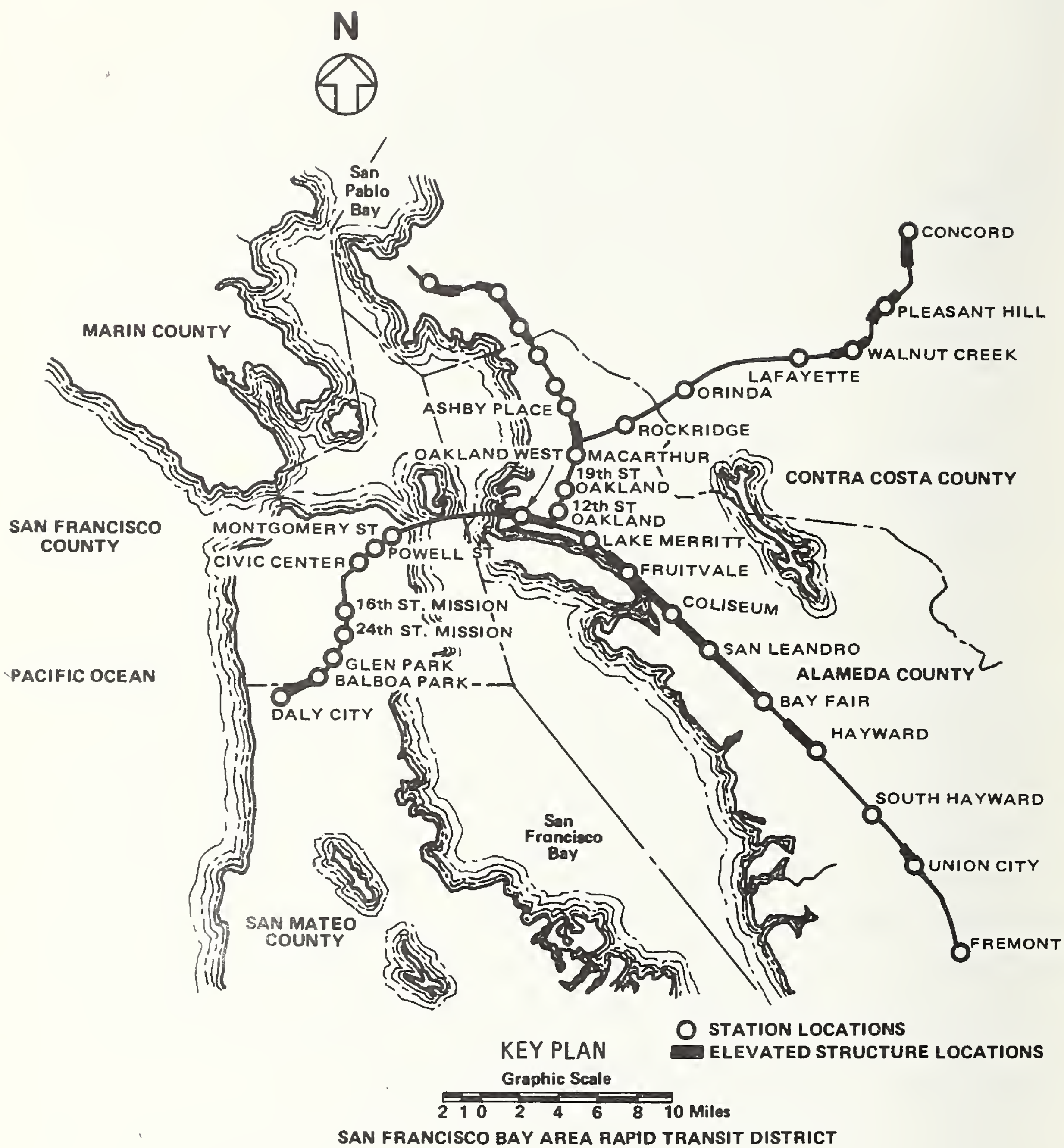


FIGURE C-1. BART SYSTEM SCHEMATIC

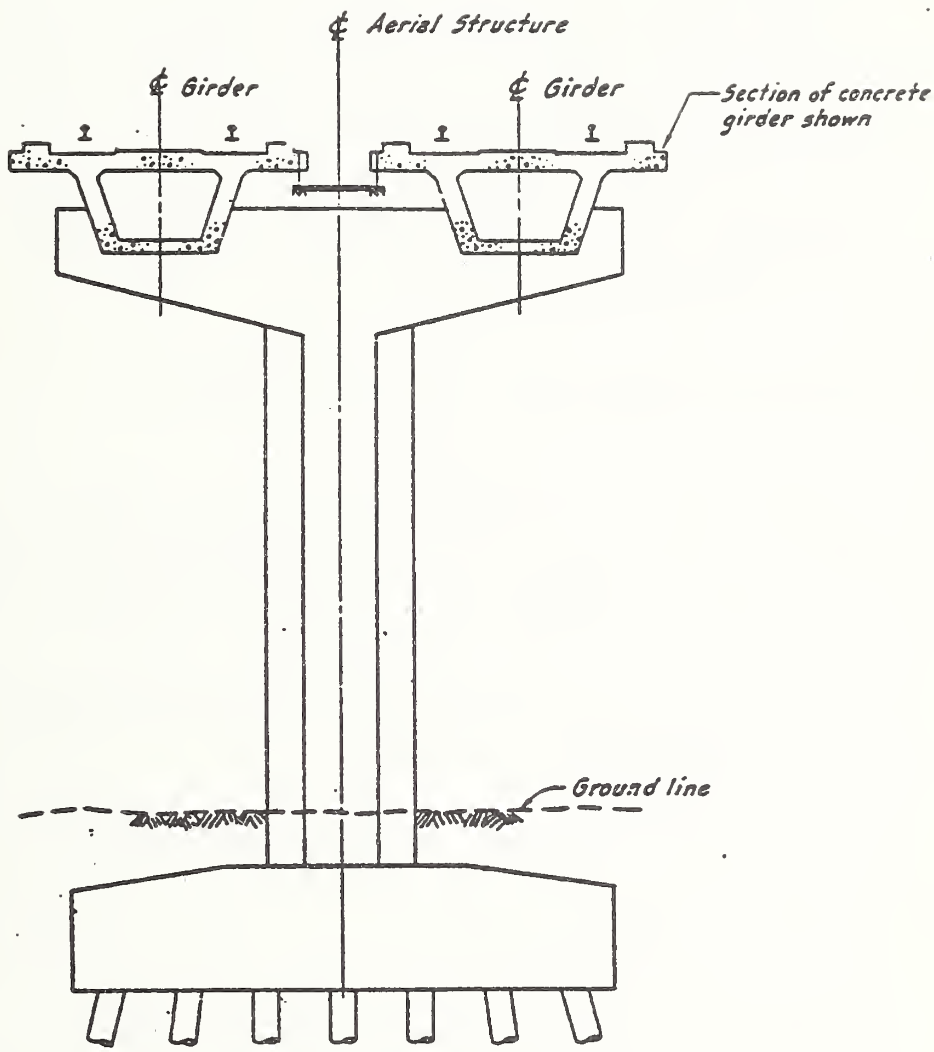


FIGURE C-2. BART AERIAL STRUCTURE STANDARD TYPICAL SECTION

studies [*C.2, C.3*] have demonstrated that BART wayside noise levels vary as 28 times the common logarithm of train speed. Thus, a maximum passby noise level of 83 dBA at 15 m (50 ft) is taken as typical for 64 km/h (40 mph) operation within 610 m (2000 ft) of BART aerial stations.

The approximate conversion from maximum (peak) sound level, L_{max}, to single event noise exposure level, SENEL, is accomplished by use of the relation [*C.4*]:

$$\text{SENEL (d)} = L_{max} \text{ (d)} + 10 \log \frac{11.3 \text{ d}}{\text{v}} , \tag{C.1}$$

where SENEL (d) is the single event noise exposure level in dBA, at a distance d. L_{max} (d) is the maximum (peak) passby noise level in dBA, at a distance d; d is the distance to track centerline, in m; and v is the train speed, in km/h.

Application of equation (C.1) to BART yields the following results for trains with 4.5 cars:

SENEL (15 m) = 92 dBA at 129 km/h (80 mph),

and

SENEL (15 m) = 87 dBA at 64 km/h (40 mph).

The day-night average sound level, L_{dn}, is found by summing the sound energy of all train passbys, with a 10 dB penalty added to nighttime (10 p.m. to 7 a.m.) operations, and averaging the result over a 24-hr period. Since the baseline SENEL values are for a 4.5-car train, an adjustment must be made to account for the total number of cars per day. The L_{dn}, thus, may be computed from:

$$L_{dn}\ (15\ m) = \text{SENEL}\ (15\ m) +$$

$$10 \log \frac{c_{day}N_{day} + 10\ c_{night}N_{night}}{4.5} - 49.4\ , \qquad (C.2)$$

where L_{dn} (15 m) is the day-night average sound level, in dB, at 15 m from the track centerline. SENEL (15 m) is the single event noise exposure level, in dBA, at 15 m from the track centerline; c_{day} is the average number of cars per train during day (7 a.m. to 10 p.m.); c_{night} is the average number of cars per train during night (10 p.m. to 7 a.m.). N_{day} is the number of train passbys during day, and N_{night} is the number of train passbys during night.

Based on BART schedule data for the three major routes [*C.5*], one may obtain the results shown below:

a. Fremont-Daly City Line:

$N_{day} = 116$, $N_{night} = 20$

$c_{day} = 5.48$, $c_{night} = 7.20$

L_{dn} (15 m) = 69 dB at 129 km/h (80 mph)

= 64 dB at 64 km/h (40 mph).

b. Concord-Daly City Line:

$N_{day} = 140$, $N_{night} = 30$

$c_{day} = 6.97$, $c_{night} = 7.80$

L_{dn} (15 m) = 71 dB at 129 km/h (80 mph)

= 66 dB at 64 km/h (40 mph).

c. Fremont-Richmond Line:

$N_{day} = 136$, $N_{night} = 30$

$c_{day} = 3.66$, $c_{night} = 3.33$

L_{dn} (15 m) = 68 dB at 129 km/h (80 mph)

= 63 dB at 64 km/h (40 mph).

In order to determine the total L_{dn} for the various segments of the transit system, the above results are combined for co-linear route segments, with the following results:

d. Daly City-MacArthur:

L_{dn} (15 m) = 73 dB at 129 km/h (80 mph)

= 68 dB at 64 km/h (40 mph).

e. Richmond-MacArthur:

L_{dn} (15 m) = 68 dB at 129 km/h (80 mph)

= 63 dB at 64 km/h (40 mph).

f. Concord-MacArthur:

L_{dn} (15 m) = 71 dB at 129 km/h (80 mph)

= 66 dB at (40 mph).

g. Fremont-Oakland Junction:

L_{dn} (15 m) = 72 dB at 129 km/h (80 mph)

= 67 dB at 64 km/h (40 mph).

L_{dn} beyond 15 m (50 ft) is calculated assuming a decrease proportional to 10 log (distance).

C.3 Fractional Impact Analysis

The fractional impact analysis here is accomplished by the method outlined by Schultz [*C.6*], which consists of the steps described below:

1. Ambient noise levels without BART are estimated based on data for average daytime levels L_d [*C.3*]. Ambient L_{dn} values are estimated by adding 2.5 dB to the L_d, since L_{dn} is typically 2 to 3 dB higher than the L_d [*C.3*]. Thus, for example, for areas along the transit corridor with an L_d of 60 to 65 dB, the average L_{dn} is estimated to be 65 dB.

2. L_{dn} contour distances are determined in intervals of 5 dB (or less) extending between 30 m (100 ft) from the aerial structure, up to the distance at which the BART L_{dn} is 5 dB below the average ambient L_{dn}. Since only about 25 residential buildings are located within 30 m (100 ft) of the transit structure [*C.7*], their omission does not significantly affect the analysis results.

3. Utilizing BART route maps [*C.2*], along with data on land use and population [*C.5*], the elevated structure portions of the system are divided into segments of constant characteristics (ambient L_{dn}, transit L_{dn}, population density, land use).

4. For each system segment, the number of impacted people is estimated by multiplying the population density by the residential land area within each transit L_{dn} range. This result is then reduced by one-half, as suggested by Schultz [*C.6*], to account for the assumption that only that half of the people that face the tracks are significantly impacted.

5. The Sound Level Weighted Population (LWP) for each route segment is then calculated by multiplying the population values by the associated noise weighting function (W) for the average transit L_{dn} in each range. The total LWP for the BART system elevated structures is then calculated by summing these results over the entire length of elevated structure.

The results of the fractional impact analysis for the BART elevated structures are summarized in Table C.1. The estimated number of people exposed to various levels of BART elevated structure transit noise is given below.

Transit L_{dn} (dB)	*Exposed Population*
70 to 75	25
65 to 70	1,510
60 to 65	7,320
55 to 60	8,850.

TABLE C-1. BART ELEVATED TRANSIT STRUCTURE NOISE IMPACT SUMMARY

Elevated Structure Location	Residential Frontage, in km (miles)	Impacted Residential Area, in sq km (sq miles)	Impacted Population	Sound Level Weighted Population (LWP)
Daly City-MacArthur	4.3 (2.7)	1.06 (0.41)	3,244	1,180
Richmond-MacArthur	8.9 (5.5)	2.12 (0.82)	6,802	1,414
Concord-MacArthur	5.1 (3.2)	1.29 (0.50)	1,313	289
Fremont-Oakland Junction	12.2 (7.6)	3.19 (1.23)	6,327	1,720
Total	30.6 (19.0)	7.67 (2.96)	17,686	4,603

REFERENCES — APPENDIX C

C.1 Wilson, Ihrig & Associates, "Noise Assessment of the Bay Area Rapid Transit System," U.S. Department of Transportation, Office of Technology Development and Deployment, Office of Rail and Construction Technology, Rept. No. UMTA-MA-06-0025-78-10 (October 1978).

C.2 Gruen Associates, Inc. & DeLeuw, Cather & Co., "BART Impact Program: Environment Project — Preliminary Findings — Sound," U.S. Department of Transportation/U.S. Department of Housing & Urban Development, Rept. No. TM 13-4-75 (March 1975).

C.3 Bolt Beranek and Newman Inc., "Acoustic Impacts of BART: Interim Service Findings," U.S. Department of Transportation/U.S. Department of Housing & Urban Development, Rept. No. TM 16-4-76 (March 1976).

C.4 U.S. Department of Transportation, "Final Environmental Impact Statement — Orange Line Relocation and Arterial Street Construction (Southwest Corridor Project)," UMTA Project No. MA-23-9007, FHWA Project No. U-393(1), Appendix H (March 1978).

C.5 Chisholm, G. *et al.*, "National Assessment of Urban Rail Noise," U.S. Department of Transportation, Urban Mass Transportation Administration, Rept. No. UMTA-MA-06-0099-79-2 (March 1979).

C.6 Schultz, T.J., "Noise Rating Criteria for Elevated Rapid Transit Structures," BBN Rept. No. 3905 (April 1979).

C.7 McCutchen, W.R. (BART), letter to D.A. Towers (BBN), (24 July 1979).

APPENDIX D: CTA INVENTORY

D.1 Elevated Structure Description

The Chicago Transit Authority (CTA) system contains approximately 52.3 km (32.5 miles) of elevated structure at locations shown in Fig. D.1. These structures can be grouped into three general categories, as described below.

1. *Open Deck (Wood Tie) Structure with Steel Solid Web Girders.* This is the predominant type, comprising about 43.5 km (27 miles) of elevated structure. This type of structure is typically supported by steel bents with plate or webbed girder columns; however, concrete piers support the structure along short segments of the Milwaukee Service and Englewood Service. The predominant stringer depth is 122 cm (48 in.), although stringer depths of 61 and 91 cm (24 and 36 in.) are also encountered on some short segments. The smaller 61 and 91 cm (24 and 36 in.) stringers consist of wide-flange beams, whereas the 122 cm (48 in.) stringers consist of plate girders. The structure deck is open, with wood ties fastened directly to the stringers. The rails are jointed and are aligned directly over the stringers, except for the Lake Service line, where the rails are offset 15 cm (6 in.) inside of the stringers (see Fig. D-2). Resilient rail fasteners have been installed in a few limited locations; however, these are not considered in the present impact evaluation.

2. *Open Deck (Wood Tie) Structure with Steel Lattice Web Girders.* This type of structure comprises about 2.2 km (4.5 miles) of the system, primarily near the Loop and along the Jackson Park Service. Steel bents support the stringers, which in turn support the open deck (wood tie) and jointed rails.

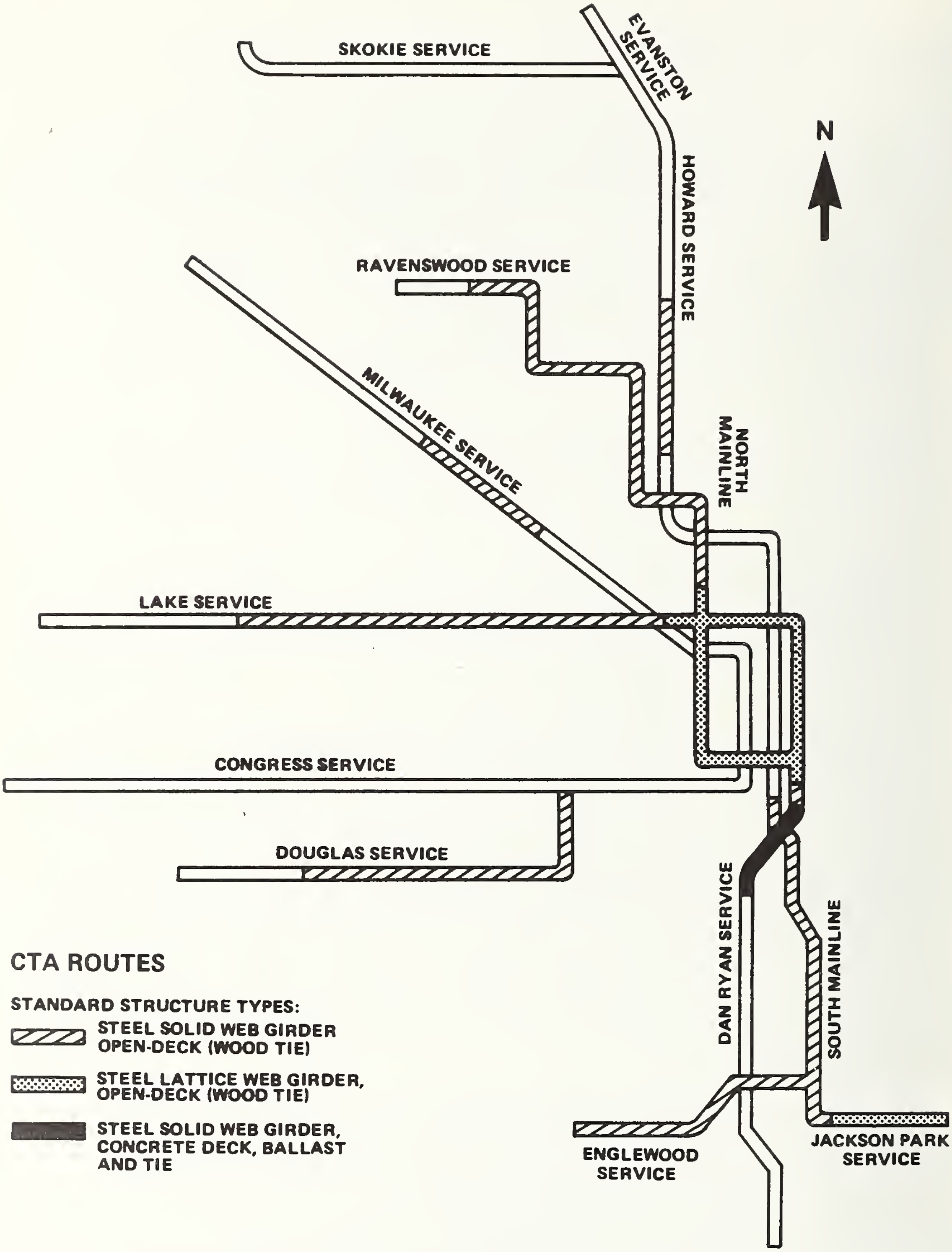


FIGURE D-1. CTA ELEVATED RAPID TRANSIT STRUCTURES

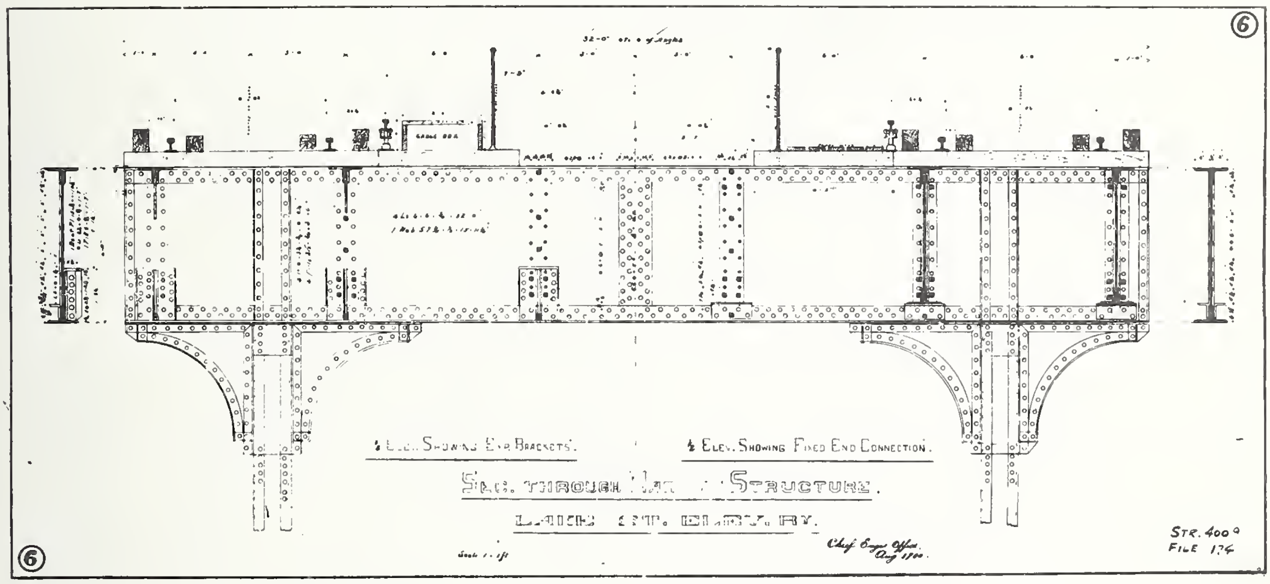


FIGURE D-2. TYPICAL SECTION OF CTA ELEVATED STRUCTURE ON THE
ON THE LAKE ST. SERVICE

3. Concrete Deck Structure with Wood Tie and Ballast Track. This type of structure comprises only about 1.6 km (1 mile) of the CTA system, along the Dan Ryan Service in the Chinatown area of Chicago. Steel columns support lateral steel girders and 142 cm (56 in.)-deep steel plate stringers with lateral steel webbed bracing. The deck is concrete and carries jointed rail on ties and ballast. Short concrete barriers, located approximately 1.8 m (6 ft) from the nearest track centerline and extending to about 0.3 m (1 ft) above the top of the rail, are situated along the two edges of the concrete deck. Figure D-3 provides typical cross-section details for this type of structure.

A structure consisting of an open deck (wood tie), supported by 46 cm (18 in.) transverse channels and steel bents, comprises only a short section of the North Side Mainline near the Loop, crossing the Chicago River. Since only one block of the commercially used area is affected by noise from this structure, it is not considered separately in the present noise impact analysis.

D.2 Noise Estimation

The estimation of L_{dn} for the CTA elevated structures is based on noise measurements made by BBN specifically for this project, during the week of 10 September 1979. Data were acquired at six locations representative of the various types of elevated structures. Photographs of the measurement sites are provided in Figs. D-4 through D-9. The measurement microphone was positioned at distances of 7.5 or 15 m (25 or 50 ft) from the centerline of the near track of the structure, at approximately rail height. At each location, approximately 12 train passages were

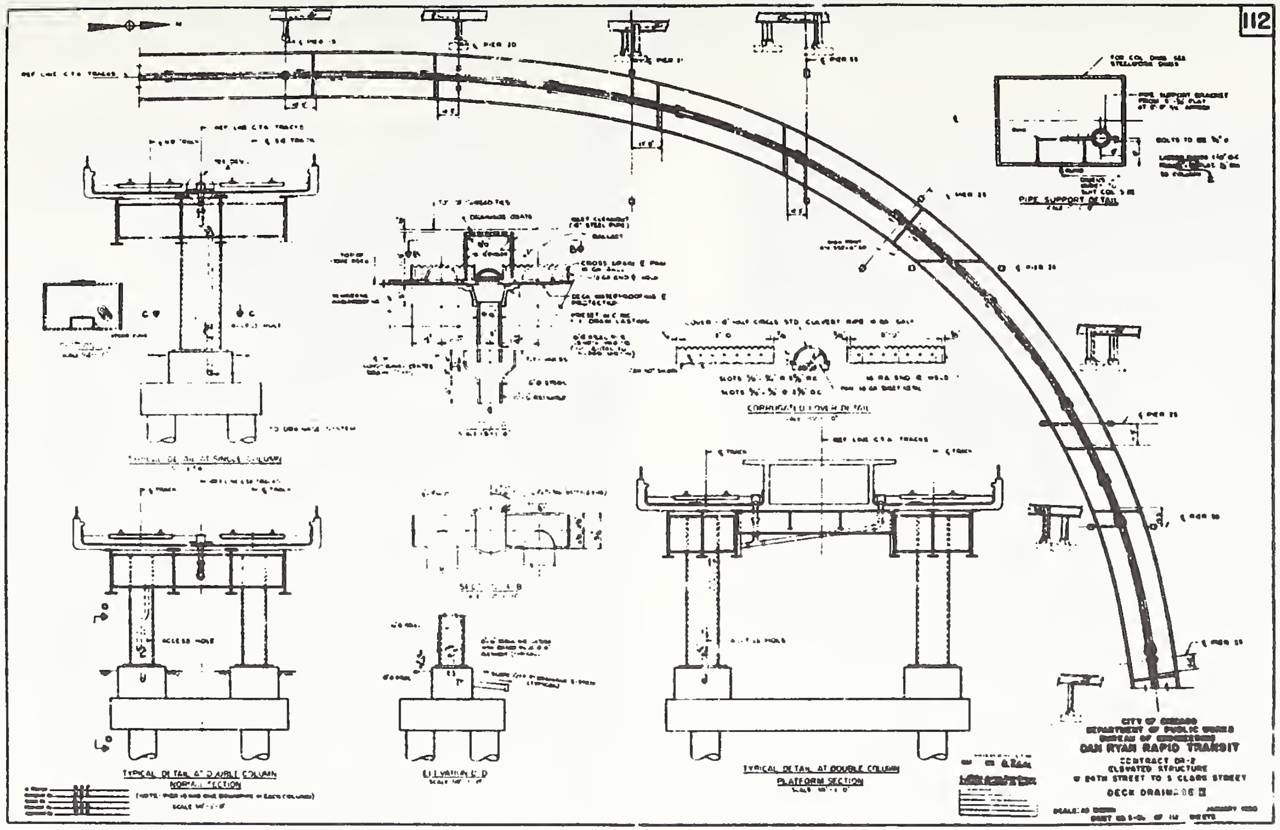
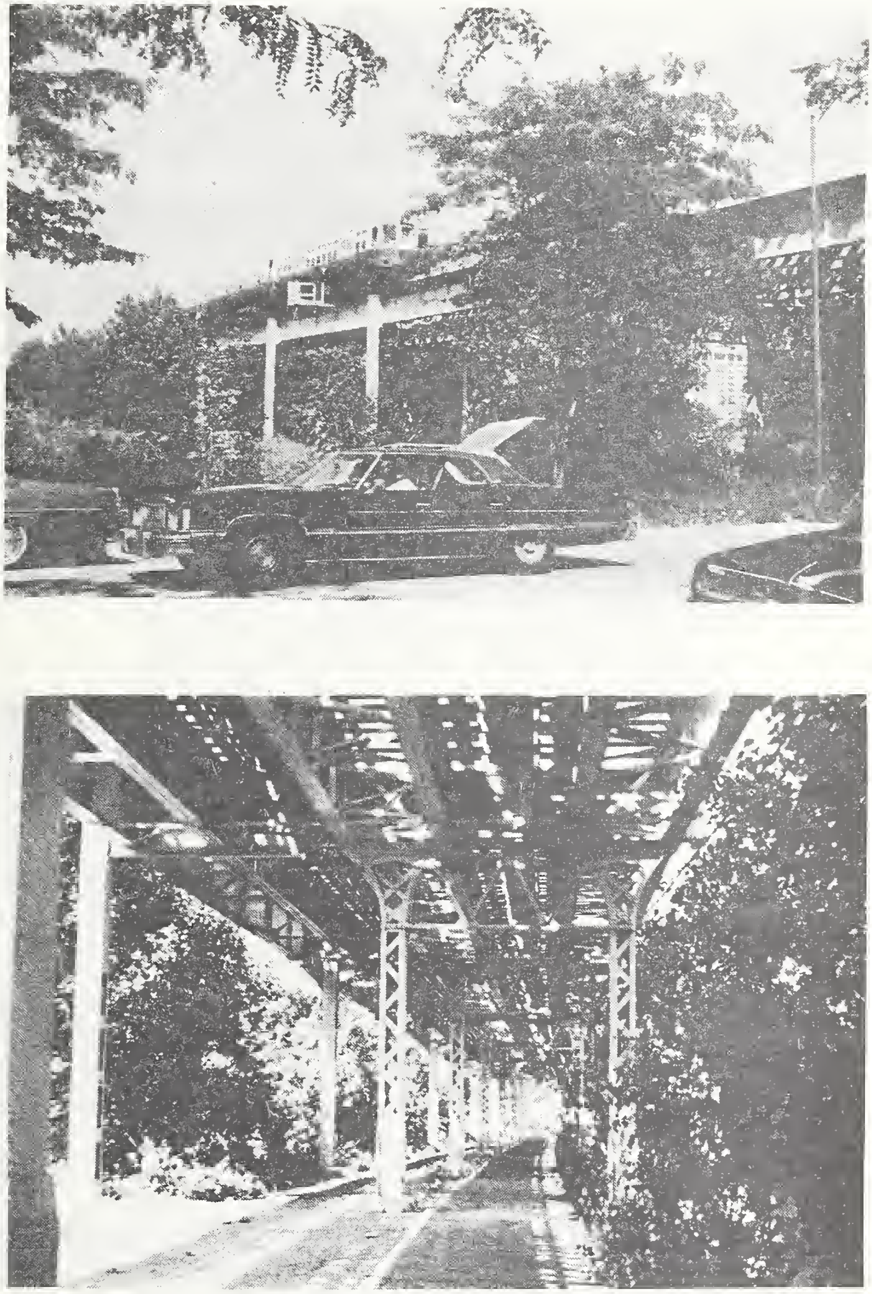


FIGURE D-3. TYPICAL DETAILS OF THE CONCRETE DECK CTA ELEVATED STRUCTURE ON THE DAN RYAN SERVICE

Note: Refer to Table D-1 for site location and structure description

FIGURE D-4. MEASUREMENT SITE 1 - JACKSON PARK SERVICE

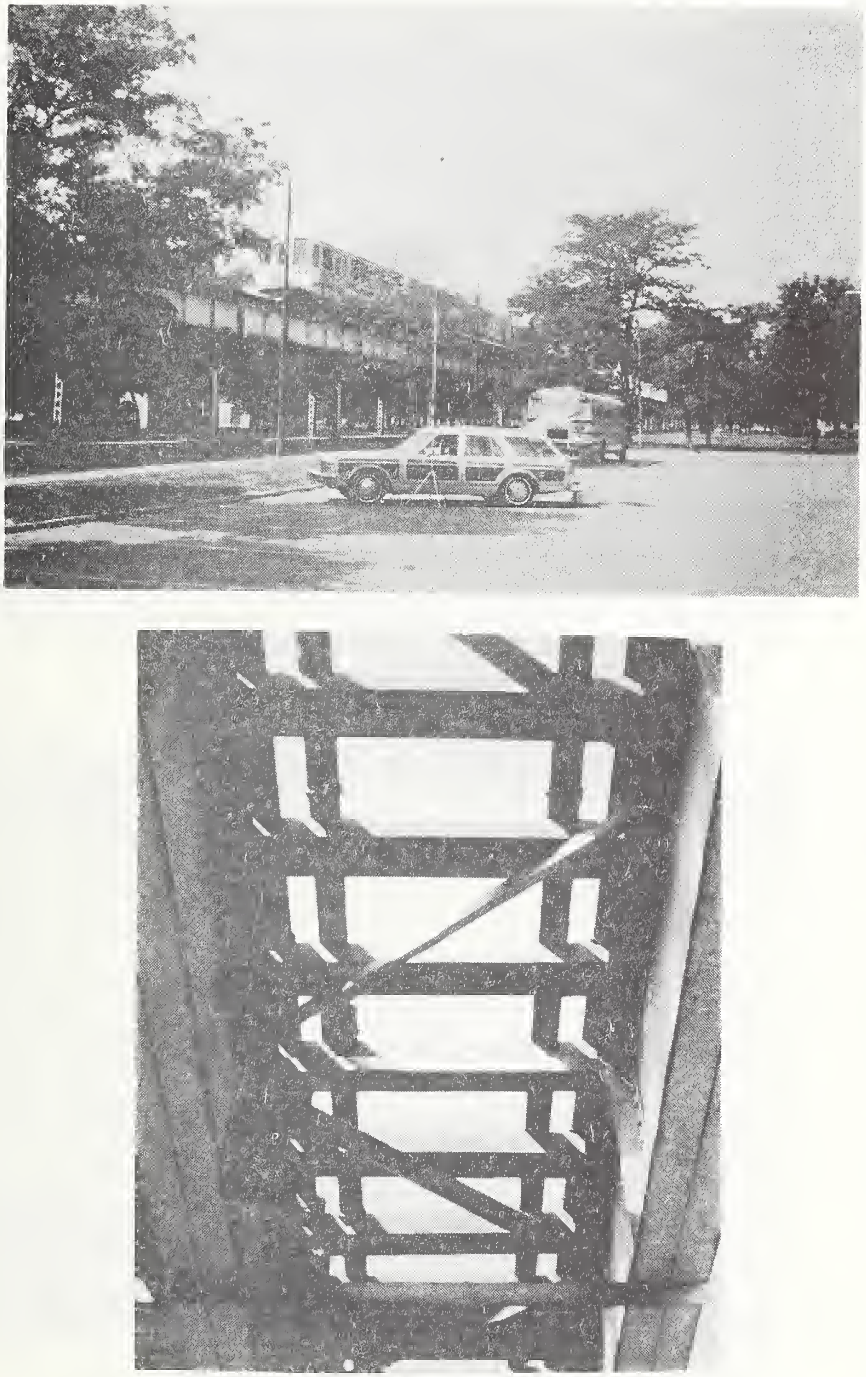


Note: Refer to Table D-1 for site location and structure description

FIGURE D-5. MEASUREMENT SITE 2 - SOUTH MAINLINE

Note: Refer to Table D-1 for site location and structure description

FIGURE D-6. MEASUREMENT SITE 3 - DAN RYAN SERVICE



Note: Refer to Table D-1 for site location and structure description

FIGURE D-7. MEASUREMENT SITE 4 - LAKE ST. SERVICE

Note: Refer to Table D-1 for site location and structure description

FIGURE D-8. MEASUREMENT SITE 5 - MILWAUKEE SERVICE

Note: Refer to Table D-1 for site location and structure description

FIGURE D-9. MEASUREMENT SITE 6 - DOUGLAS PARK SERVICE

monitored; about half were on the near track and half on the far track. Speeds were measured, and the number and type of cars were noted for each passage. Noise was measured using a BBN Model 614 Portable Noise Monitor to obtain the A-weighted maximum level (L_{max}) and the single event noise exposure level (SENEL). Tape recordings were also made for selected train passbys using a Kudelski Nagra IV-SJ tape recorder; these data were subsequently reduced in the laboratory in order to obtain spectra.

The measured L_{max} and SENEL data were normalized to "average" operating conditions, i.e., to a 4-car train at 56 km/h (35 mph), measured at a distance of 7.5 m (25 ft), using the following corrections:

a. Speed: $L_{max} \propto 30 \log (\text{speed})$
$\text{SENEL} \propto 20 \log (\text{speed})$

b. Train Length: (No L_{max} correction)
$\text{SENEL} \propto 10 \log (\text{no. of cars})$

c. Distance: $L_{max} \propto 10 \log (1/\text{distance})$
$\text{SENEL} \propto 10 \log (1/\text{distance})$.

The normalized data were averaged logarithmically for each measurement site. The results are summarized in Table D.1. Typical noise spectra for train passbys on CTA elevated structures are presented in Fig. D.10.

The A-weighted noise level data for sites 2, 4, 5, and 6 are clustered within a 2-3 dB range; the structures at these sites are all open deck (wood tie) types. The structure at site 2 represents the predominant steel structure type, with 122 cm (48 in.) plate

TABLE D-1. CTA TRANSIT SYSTEM ELEVATED STRUCTURE NOISE MEASUREMENT SUMMARY

Site	Elevated Line	Location Description	Structure Type	Average Normalized Noise Level* (dBA)	
				L_{max}	SENEL
1	Jackson Park Service	63rd St., 23 m (75 ft) west of Kimbark Ave. (outbound side)	122 cm (48 in.) steel lattice web girders, open deck (wood tie), jointed rail	102	107
2	South Side Mainline	State St. and 29th St. (outbound side)	122 cm (48 in.) steel plate solid web girders, open deck (wood tie), jointed rail	98	105
3	Dan Ryan Service	South Federal St. 30 m (100 ft) south of 23rd St. (inbound side)	142 cm (56 in.) steel plate solid web girders, concrete deck, wood tie and ballast, jointed rail, short barrier	89	95
4	Lake Street	Lake St., 76 m (250 ft) west of Conservatory Dr. (outbound side)	122 cm (48 in.) steel plate solid web girders, open deck (wood tie), jointed rail offset 1.5 cm (6 in.) inside stringers	100	106
5	Milwaukee Service	Linden Place (inbound side)	122 cm (48 in.) steel girders, open deck (wood tie), jointed rail (concrete pier support)	98	103
6	Douglas Park Service	14th Pl. and Paulina Ave. (outbound side)	91 cm (36 in.) wide flange steel solid web girders, open deck (wood tie), jointed rail	100	103

*L_{max} or SENEL at 7.5 m (25 ft) for four-car train passby at 56 km/h (35 mph).

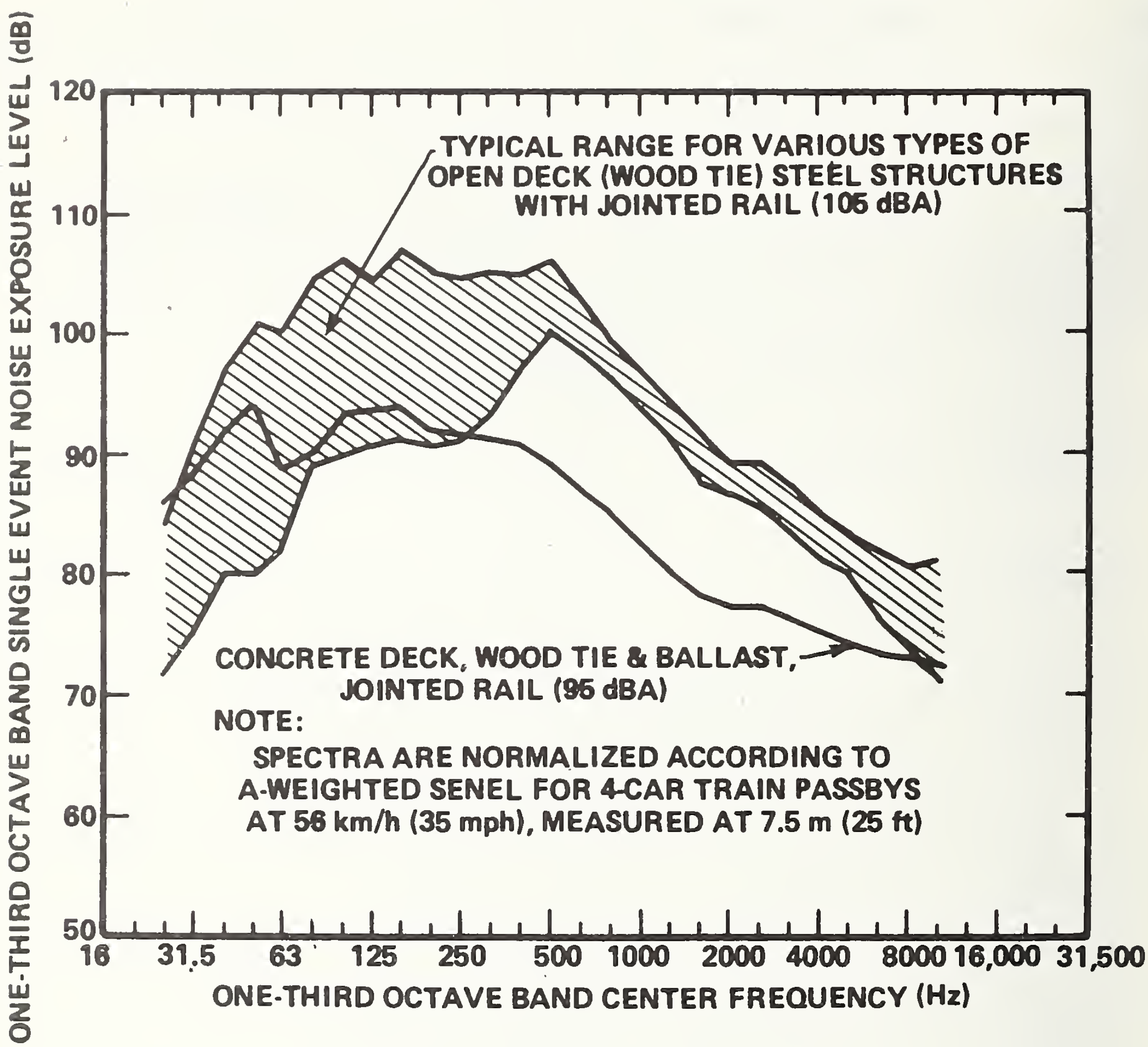


FIGURE D-10. CTA ELEVATED TRANSIT STRUCTURE RELATIVE NOISE SPECTRA

girder stringers supporting the track directly above. The structure at site 4 differs in that the rails are offset 15 cm (6 in.) inside the stringers. The structure at site 5 differs in that the substructure consists of concrete piers rather than steel bents. The structure at site 6 contains 91 cm (36 in.) wide-flange beam type stringers, rather than the typical 122 cm (48 in.) plate type. The measurement results for the above sites suggest that stringer spacing, substructure type, and stringer depth do not significantly affect the A-weighted noise levels due to CTA elevated structures, although these parameters may affect the spectrum shape at low frequencies.

The A-weighted noise level results for site 1, which is near a structure that has an open deck (wood tie) supported on steel lattice web girders, are seen to be 2 to 4 dB higher than results for similar structures with plate girders. Since one would expect lattice web girders to radiate noise less efficiently than solid web girders, this result may be due to differences in other parameters, such as rail or structural condition.

For the purpose of the present analysis, the normalized data from sites 1, 2, 4, 5, and 6 were averaged logarithmically to obtain basic levels for train passbys on all CTA open deck (wood tie) elevated structures. The resulting L_{max} of 100 dBA and SENEL of 105 dBA for a 4-car train passby at 56 km/h (35 mph), measured at 7.5 m (25 ft), serve as a basis for the estimation of L_{dn} for these structures.

The normalized data for site 3 were used for estimating noise emission associated with trains on concrete deck (wood tie and ballast) type structures. The corresponding L_{max} of

of 89 dBA and SENEL of 95 dBA for a 4-car train passby at 56 km/h (35 mph), measured at 7.5 m (25 ft), serve as a basis for the estimation of L_{dn} near this structure type.

A comparison of normalized noise level data for the near and far tracks indicates that far track noise levels are 2 to 6 dB less than the near track levels at sites 1, 2, 4, and 5, perhaps due to shielding effects. However, at site 6, the average far track levels were found to be 1 to 3 dB higher than the near track levels. This suggests that site-specific conditions affect the noise radiated from elevated structures. At site 3, normalized far track noise levels are 2 to 3 dB above the near track levels, possibly because the low barrier there has a greater effect on near track noise from wheel/rail interaction than on similar far track noise. In view of these considerations and the approximate nature of an impact analysis, near and far track normalized data were averaged for the purpose of obtaining basic noise levels for train operations on the CTA elevated structures.

As a check on the validity of the speed normalization, measured data for all open deck CTA elevated structures (normalized only for distance and train length) were plotted against speed. The results shown in Fig. D.11 suggest that L_{max} varies as 28 log (speed), which is close to the typical 30 log (speed) relationship. Figure D.12 indicates that SENEL varies as 23 log (speed), comparable to the typical 20 log (speed) relationship. In view of the data scatter, the typical 30 log (speed) and 20 log (speed) relationships were justifiably used in this analysis for normalization of L_{max} and SENEL data, respectively.

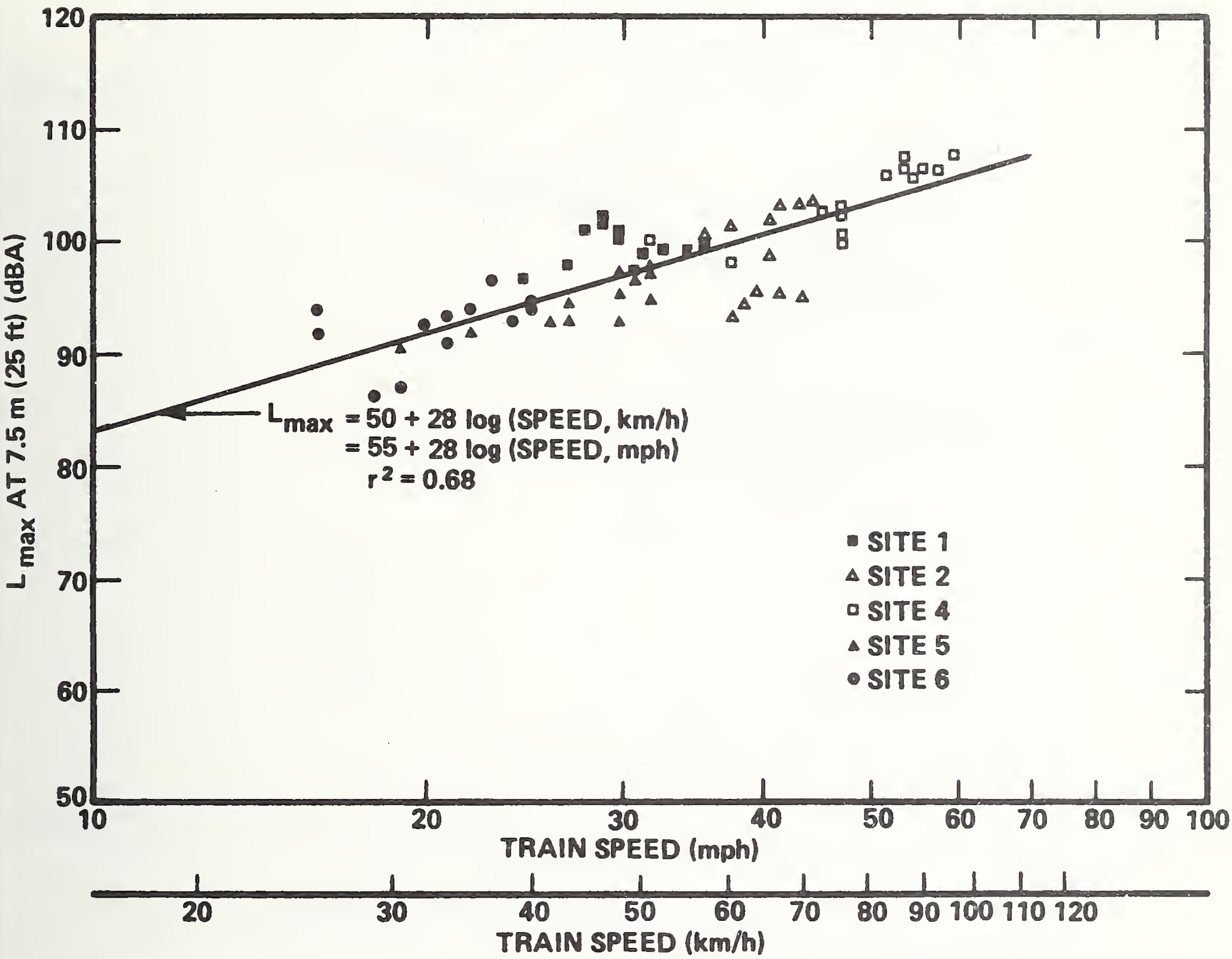


FIGURE D-11. CTA NOISE MEASUREMENTS: L_{MAX} VS SPEED ON ELEVATED STRUCTURES WITH STEEL WEB GIRDERS, OPEN DECK (WOOD TIE), JOINTED RAIL

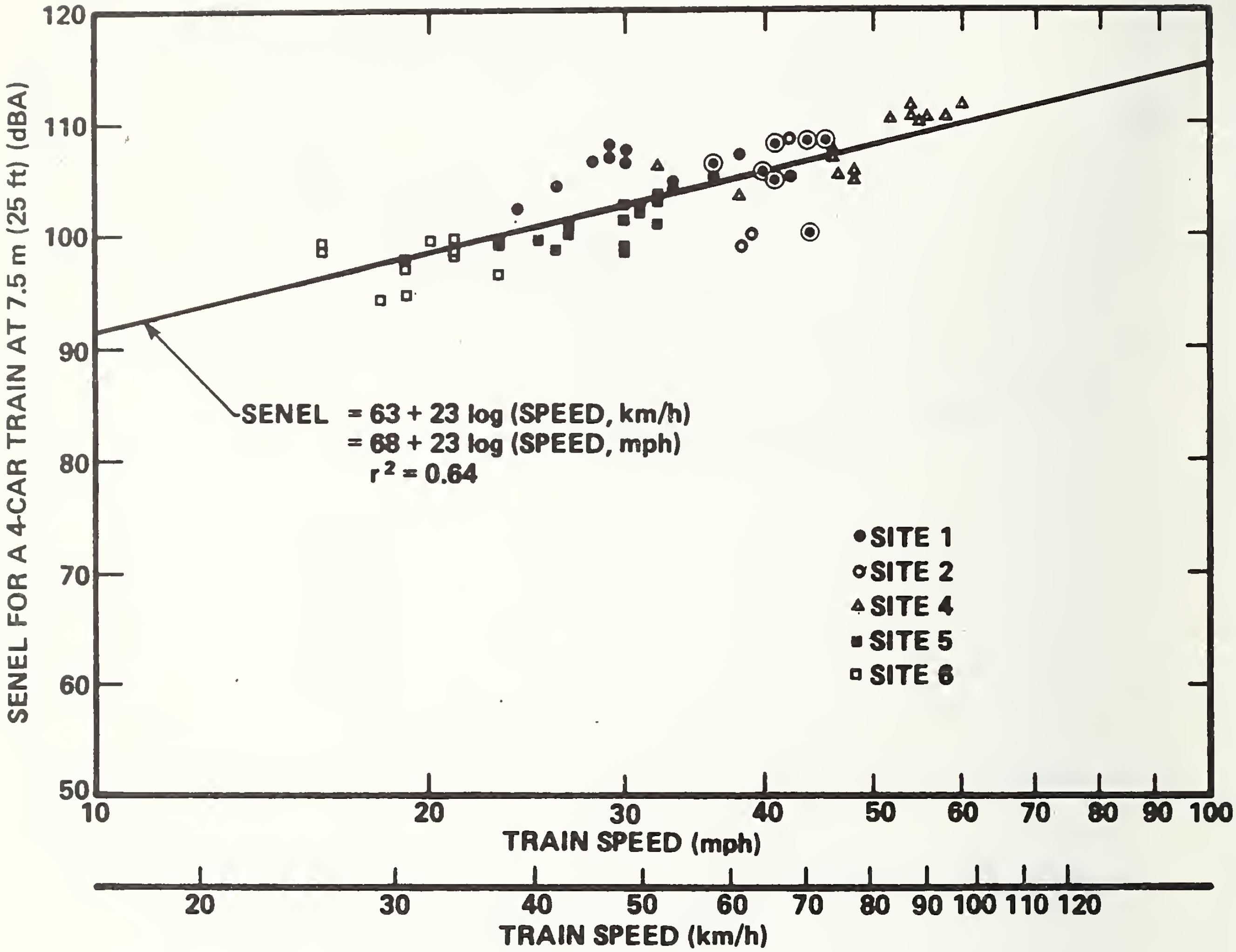


FIGURE D-12. CTA NOISE MEASUREMENTS: SENEL VS SPEED ON ELEVATED STRUCTURES WITH STEEL WEB GIRDERS, OPEN DECK (WOOD TIE), JOINTED RAIL

The day-night average sound level, L_{dn}, is calculated by summing the sound energy of all train passbys, with a 10 dB penalty added to nighttime (10 p.m. to 7 a.m.) operations, and averaging the result over a 24-hr period. Thus:

$$L_{dn}(7.5\ \text{m}) = \text{SENEL(norm.)} + 10 \log [N_{day} + 10N_{night}] - 49.4, \quad \text{(D.1)}$$

where $L_{dn}(7.5\ \text{m})$ is the day-night average sound level, in dB, at a distance of 7.5 m (25 ft) from track centerline; SENEL(norm.) is the single event noise exposure level, in dBA, for a typical train passby at 7.5 m (25 ft); N_{day} is the number of train passbys in daytime (7 a.m. to 10 p.m.); and N_{night} is the number of train passbys at nighttime (10 p.m. to 7 a.m.).

Information supplied by the CTA [*D.1*], along with the BBN field observations, indicates that a typical train consists of 4 cars and operates at an average speed of 56 km/h (35 mph). Train frequency, calculated from weekday average system headways [*D.2*], indicates 134 daytime and 27 nighttime train passbys in each direction on each transit line. Based on these numbers, the single-track (one-direction) L_{dn} calculated from Eq. D.1 turns out to be 82 dB for open deck (wood tie) structures and 72 dB for concrete deck structures, corresponding to an observation distance of 7.5 m (25 ft).

The actual L_{dn} at a given location is calculated by logarithmic addition of the near and far track L_{dn} contributions at the appropriate distances, assuming that noise levels vary as 10 log (1/distance). An average track separation of 7.5 m (25 ft) is assumed, on the basis of an on-site inspection [*D.2*] and field observations. The L_{dn} estimation model for CTA elevated structures is illustrated in Fig. D-13.

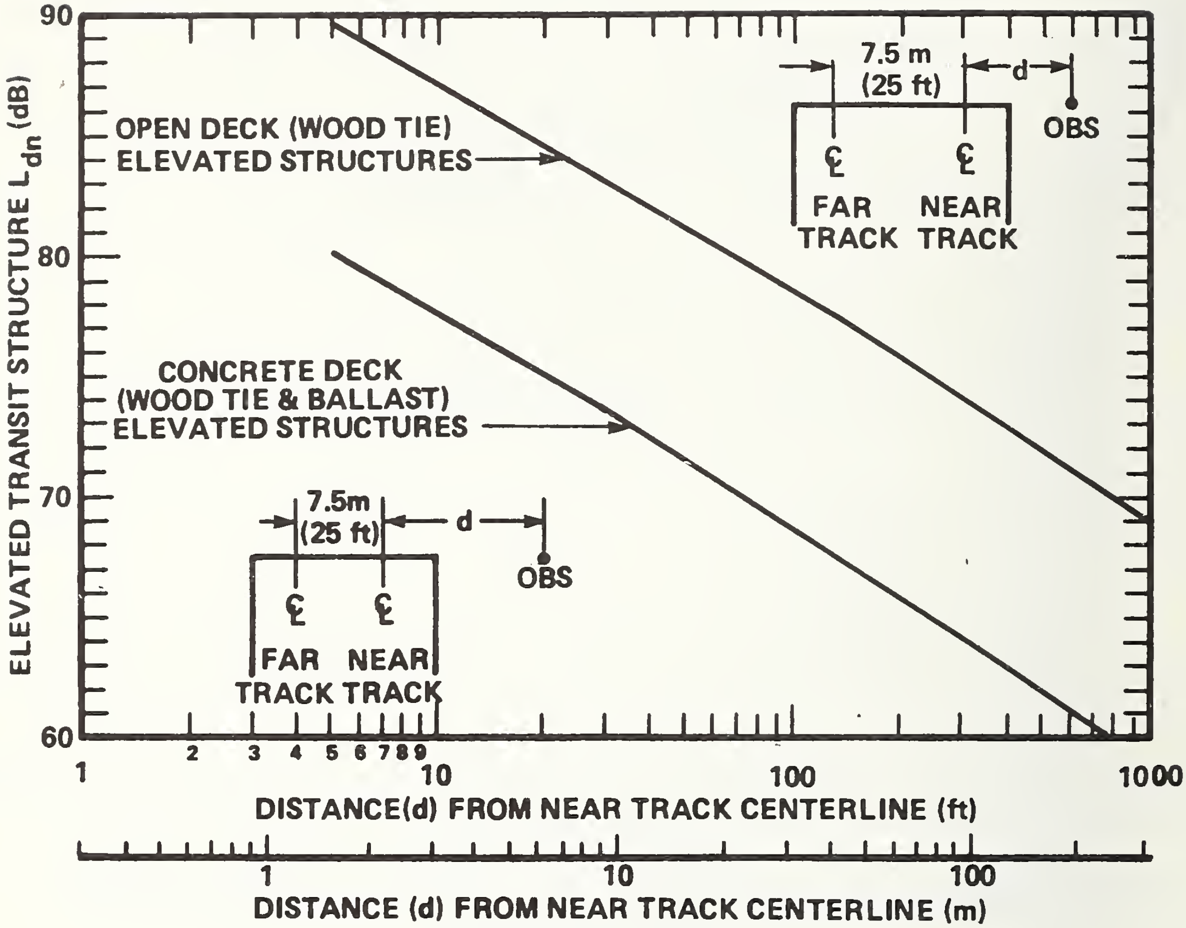


FIGURE D-13. ESTIMATION OF L_{dn} FOR CTA TRANSIT SYSTEM ELEVATED STRUCTURES

D.3 Fractional Impact Analysis

The fractional impact analysis for the CTA elevated structures is accomplished by the method outlined by Schultz [*D.3*]. The steps in this procedure are described as follows:

1. The transit L_{dn} component is estimated by the method outlined previously, for distances corresponding to the first row of residential and commercial buildings. These distances are obtained from a physical inventory [*D.2*].

2. The population for each block along the elevated lines is obtained from the inventory [*D.2*], which determined an average of 0.2 people per ft of frontage per story.

3. The Sound Level Weighted Population (LWP) for each segment between elevated line stations is calculated by multiplying the population bordering the segment by the noise weighting function (W) corresponding to the transit L_{dn} for the appropriate structure type at each residential/commercial location.

4. The total LWP is calculated for each elevated line, for each structural type, and for the entire system by summing the LWPs for the appropriate station-to-station segments. Results are obtained for the following two cases: (a) residential and commercial land uses impacted and (b) only residential land uses impacted.

The above procedure assumes that train noise is never more than 5 dB below the ambient L_{dn} (without trains) at the first row of buildings. The lowest train L_{dn} component encountered in the calculations is 68.5 dB, with most levels in the 80 to 85 dB range. Population data indicate that the population density in Chicago in 1975 was 13,911 people per square mile [*D.4*].

Ambient levels, estimated from the relation [*D.5*]

$$L_{dn} = 10 \log (\rho) + 22 \text{ dB} ,$$

where ρ denotes population density (people per square mile), were found to be on the order of 63 dB; short-term (17 to 35 min) noise samples, taken during the field measurements between train passbys, indicated L_{eq}'s ranging between 60 and 67 dBA. Therefore, the fractional impact analysis should include all locations exposed to a transit L_{dn} of 58 dB or greater. Since the lowest train noise encountered was 68.5 dB, the assumption of train noise dominance is justifiable.

The results of the fractional impact analysis for the CTA system elevated structures are summarized in Tables D-2, D-3, and D-4. Table D-5 provides noise impact calculation details for each transit line and structure type on a station-to-station basis.

REFERENCES — APPENDIX D

D.1. Keevil, W.R., Chicago Transit Authority, letter to E.E. Ungar, Bolt Beranek and Newman Inc. (26 December 1978).

D.2. Amman & Whitney Consulting Engineers, "Noise Control Design of Elevated Structures — Draft Inventory Report — Chicago Transit System" (28 September 1979).

D.3. Schultz, T.J., "Noise Rating Criteria for Elevated Rapid Transit Structures," BBN Rept. No. 3905 (April 1979).

D.4. U.S. Department of Commerce, Bureau of the Census, "County and City Data Book 1977 — A Statistical Abstract Supplement," (1977).

D.5. U.S. Environmental Protection Agency, "Population Distribution of the United States as a Function of Outdoor Noise Level," Rept. No. EPA-550/9-74-009A (June 1974).

TABLE D-2. CTA SYSTEM ELEVATED STRUCTURE FRACTIONAL IMPACT ANALYSIS SUMMARY

Elevated Line	Structure Type	Impacted Population (P)		Sound Level Weighted Population (LWP)	
		Residential and Commercial	Residential Only	Residential and Commercial	Residential Only
Dan Ryan Service	Open deck (wood tie), solid web girders	1,020	413	1,843	613
	Open deck (wood tie), lattice web girders	972		1,582	
	Concrete deck, wood tie & ballast track	364	364	244	244
	Total Line	2,356	777	3,669	857
Lake Street Service	Open deck (wood tie), solid web girders	11,902	8,810	17,120	12,902
	Open deck (wood tie), lattice web girders	659		1,144	
	Total Line	12,561	8,810	18,264	12,902
Milwaukee Service	Open deck (wood tie), solid web girders	5,090	4,477	9,633	8,405
Douglas Park Service	Open deck (wood tie), solid web girders	11,848	11,383	21,230	20,316
Jackson Park Service	Open deck (wood tie), solid web girders	1,188	1,188	1,672	1.672
	Open deck (wood tie), lattice web girders	3,161	930	5,866	1,620
	Total Line	4,349	2,118	7,538	3,292
Englewood Service	Open deck (wood tie), solid web girders	7,391	5,828	13,177	10,279
Ravenswood Service	Open deck (wood tie), solid web girders	11,674	10,512	20,911	18,580
Loop Service	Open deck (wood tie), lattice web girders	47,779	4,314	80,020	7,105
North Side Mainline	Open deck (wood tie), solid web girders	20,539	17,233	35,701	29,560
	Open deck (wood tie), lattice web girders	4,758	428	8,540	779
	Total Line	25,297	17,661	44,241	30,339
South Side Mainline	Open deck (wood tie), solid web girders	12,753	12,008	18,780	17,459
Miscellaneous	Open deck (wood tie), solid web girders	83,405	71,852	140,067	119,786
Miscellaneous	Open deck (wood tie), lattice web girders	57,329	5,672	97,152	9,504
Dan Ryan Service	Concrete deck, wood tie and ballast track	364	364	244	244
ALL LINES	ALL TYPES	141,098	77,888	237,463	129,534

TABLE D-3. COMMERCIAL AND RESIDENTIAL POPULATION VS NOISE EXPOSURE FOR CTA SYSTEM ELEVATED STRUCTURES

Elevated Line	Structure Type	Number of People Exposed to Elevated Transit Structure Noise Within Various Ranges of L_{dn}, in dB					
		65-70	70-75	75-80	80-85	85-90	Total
Dan Ryan Service	Open deck, solid web girders			304		716	1,020
	Open deck, lattice web girders				972		972
	Concrete deck, tie & ballast	182	182				364
	Total Line	182	182	304	972	716	2,356
Lake Street Service	Open deck, solid web girders		1,483	2,109	8,310		11,902
	Open deck, lattice web girders				659		659
	Total Line		1,483	2,109	8,969		12,561
Milwaukee Service	Open deck, solid web girders			167	2,675	2,248	5,090
Douglas Park Service	Open deck, solid web girders			143	8,332	3,373	11,848
Jackson Park Service	Open deck, solid web girders			594	594		1,188
	Open deck, lattice web girders			238	2,923		3,161
	Total Line			832	3,517		4,349
Englewood Service	Open deck, solid web girders		235	598	3,832	2,726	7,391
Ravenswood Service	Open deck, solid web girders			321	7,117	4,236	11,674
Loop Service	Open deck, lattice web girders			3,096	44,683		47,779
North Side Mainline	Open deck, solid web girders			2,998	11,991	5,550	20,539
	Open deck, lattice web girders				4,758		4,758
	Total Line			2,998	16,749	5,550	25,297
South Side Mainline	Open deck, solid web girders			7,763	4,907	83	12,753
Miscellaneous	Open deck, solid web girders		1,718	14,997	47,758	18,932	83,405
Miscellaneous	Open deck, lattice web girders			3,334	53,995		57,329
Dan Ryan Service	Concrete deck, tie & ballast	182	182				364
ALL LINES	ALL TYPES	182	1,900	18,331	101,753	18,932	141,098

TABLE D-4. RESIDENTIAL POPULATION VS NOISE EXPOSURE FOR CTA SYSTEM ELEVATED STRUCTURES

Elevated Line	Structure Type	Number of People Exposed to Elevated Transit Structure Noise Within Various Ranges of L_{dn}, in dB					
		65-70	70-75	75-80	80-85	85-90	Total
Dan Ryan Service	Open deck, solid web girders			304		109	413
	Open deck, lattice web girders						0
	Concrete deck, tie & ballast	182	182				364
	Total Line	182	182	304		109	777
Lake Street Service	Open deck, solid web girders		1,483	2,109	5,218		8,810
	Open deck, lattice web girders						0
	Total Line		1,483	2,109	5,218		8,810
Milwaukee Service	Open deck, solid web girders			167	2,394	1,916	4,477
Douglas Park Service	Open deck, solid web girders			143	8,200	3,040	11,383
Jackson Park Service	Open deck, solid web girders			594	594		1,188
	Open deck, lattice web girders			238	692		930
	Total Line			832	1,286		2,118
Englewood Service	Open deck, solid web girders		235	384	3,473	1,736	5,828
Ravenswood Service	Open deck, solid web girders			321	7,026	3,165	10,512
Loop Service	Open deck, lattice web girders				4,314		4,314
North Side Mainline	Open deck, solid web girders			2,848	10,109	4,276	17,233
	Open deck, lattice web girders				428		428
	Total Line			2,848	10,537	4,276	17,661
South Side Mainline	Open deck, solid web girders			7,574	4,434		12,008
Miscellaneous	Open deck, solid web girders		1,718	14,444	41,448	14,242	71,852
Miscellaneous	Open deck, lattice web girders			238	5,434		5,672
Dan Ryan Service	Concrete deck, tie & ballast	182	182				364
ALL LINES	ALL TYPES	182	1,900	14,682	46,382	14,242	77,888

TABLE D-5. CTA NOISE IMPACT CALCULATIONS

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit Ldn (dB)	W (Ldn)	Impacted Population (P) Residential & Commercial	Impacted Population (P) Residential Only	Sound Level Weighted Population (LWP) Residential & Commercial	Sound Level Weighted Population (LWP) Residential Only
Dan Ryan Service								
Open Deck, Lattice Web Girders								
Loop - Cermak	1,320	40	82.0	1.628	972	---	1,582	---
Open Deck, Solid Web Girders								
Loop - Cermak	5,280	15	85.5	2.027	716	109	1,451	221
		100	78.5	1.289	304	304	392	392
Total Structure	5,280				1,020	413	1,843	613
Concrete Web, Solid Web Girders								
Loop - Cermak	5,280	50	71.5	0.756	182	182	138	138
		100	68.5	0.580	182	182	106	106
Total Structure	5,280				364	364	244	244
TOTAL LINE	11,880				2,356	777	3,669	857
Lake St. Service								
Open Deck, Lattice Web Girders								
Loop - Clinton	530	30	83.0	1.736	659	---	1,144	---
Open Deck, Solid Web Girders								
Loop - Clinton	1,120	30	83.0	1.736	1,101	---	1,911	---
Clinton - Ashland	6,270	30	83.0	1.736	359	90	623	156
		50	81.0	1.526	269	269	410	410
Subtotal					628	359	1,033	566
Ashland - California	6,765	30	83.0	1.736	2,109	2,028	3,661	3,521
		40	82.0	1.628	318	318	518	518
		75	79.5	1.380	1,114	1,114	1,537	1,537
		100	78.5	1.289	995	995	1,283	1,283
		150	72.0	0.788	1,483	1,483	1,169	1,169
Subtotal					6,019	5,938	8,168	8,028
California - Kedzie	2,145	30	83.0	1.736	429	343	745	595
Kedzie - Homan	1,155	30	83.0	1.736	231	115	401	200
Homan - Pulaski	3,630	30	83.0	1.736	932	517	1,618	898
Pulaski - Cicero	4,290	30	83.0	1.736	645	537	1,120	932
		35	82.5	1.682	215	107	362	180
Subtotal					860	644	1,482	1,112
Cicero - Laramie	2,980	30	83.0	1.736	447	298	776	517
		35	82.5	1.682	298	298	501	501
		40	82.0	1.628	298	298	485	485
Subtotal					1,043	894	1,762	1,503
Laramie - Grade	250	---	---	---	---	---	---	---
Total Structure	28,605				11,902	8,810	17,120	12,902
TOTAL LINE	29,135				12,561	8,810	18,264	12,902

TABLE D-5. CTA NOISE IMPACT CALCULATIONS (CONT.)

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit Ldn (dB)	W (Ldn)	Impacted Population (P): Residential & Commercial	Impacted Population (P): Residential Only	Sound Level Weighted Population (LWP): Residential & Commercial	Sound Level Weighted Population (LWP): Residential Only
Milwaukee Service Open Deck, Solid Web Girders								
Grade - California	2,500	10	87.0	2.219	500	334	1,110	741
		15	85.5	2.027	166	---	336	---
		20	84.5	1.907	83	---	158	---
		50	81.0	1.526	167	167	255	255
		200	75.5	1.039	167	167	174	174
Subtotal					1,083	668	2,033	1,170
California - Western	2,970	10	87.0	2.219	396	396	879	879
		15	85.5	2.027	396	396	803	803
		20	84.5	1.907	297	198	566	378
		25	83.5	1.791	396	297	709	532
		30	83.0	1.736	297	297	516	516
Subtotal					1,782	1,584	3,473	3,108
Western - Damen	2,970	10	87.0	2.214	169	169	375	375
		15	85.5	2.027	423	423	857	857
		25	83.5	1.791	423	423	758	758
		35	82.5	1.682	254	254	427	427
Subtotal					1,269	1,269	2,417	2,417
Damen - Grade	990	15	85.5	2.027	198	198	401	401
		20	84.5	1.907	198	198	378	378
		25	83.5	1.791	132	132	236	236
		30	83.0	1.736	198	198	344	344
		50	81.0	1.526	230	230	351	351
Subtotal					956	956	1,710	1,710
TOTAL LINE	9,430				5,090	4,477	9,633	8,405
Douglas Park Service Open Deck, Solid Web Girders								
Lake Service - Polk	4,290	10	87.0	2.219	143	143	317	317
		15	85.5	2.027	72	---	146	---
		25	83.5	1.791	215	215	385	385
		35	82.5	1.682	143	143	241	241
		40	82.0	1.682	143	143	145	145
		100	78.5	1.289	143	143	184	184
Subtotal					859	787	1,418	1,272
Polk - 18th St.	4,290	10	87.0	2.219	264	264	586	586
		15	85.5	2.027	660	531	1,338	1,076
		25	83.5	1.791	264	264	473	473
		35	82.5	1.682	264	264	444	444
Subtotal					1,452	1,323	2,841	2,579
18th St. - Hoyne	3,300	10	82.0	2.219	283	283	628	628
		15	85.5	2.027	944	944	1,913	1,913
		25	83.5	1.791	472	472	845	845
		50	81.0	1.526	189	189	288	288
Subtotal					1,888	1,888	3,674	3,674
Hoyne - Western	1,650	15	85.5	2.027	413	413	837	837
		50	81.0	1.526	990	990	1,511	1,511
Subtotal					1,403	1,403	2,348	2,348
Western - California	1,980	15	85.5	2.027	132	---	268	---
		20	84.5	1.907	132	132	252	252
		40	82.0	1.628	264	264	430	430
Subtotal					528	396	950	682

TABLE D-5. CTA NOISE IMPACT CALCULATIONS (CONT.)

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit Ldn (dB)	W (Ldn)	Impacted Population (P) Residential & Commercial	Impacted Population (P) Residential Only	Sound Level Weighted Population (LWP) Residential & Commercial	Sound Level Weighted Population (LWP) Residential Only
Douglas Park Service (Cont.)								
California - Kedzie	2,310	20 25 35	84.5 83.5 82.5	1.907 1.791 1.682	924 185 462	924 185 462	1,762 331 777	1,762 331 777
Subtotal					1,571	1,571	2,870	2,870
Kedzie - Central Park	2,310	20 25 30 50	84.5 83.5 83.0 81.0	1.907 1.791 1.736 1.526	154 308 539 770	154 308 539 770	294 552 936 1,175	294 552 936 1,175
Subtotal					1,771	1,771	2,957	2,957
Central Park - Pulaski	2,310	15 20 25 30 35 50	85.5 84.5 83.5 83.0 82.5 81.0	2.027 1.907 1.791 1.736 1.682 1.526	462 264 264 132 132 198	462 264 132 132 132 198	936 503 473 229 222 302	936 503 236 229 222 302
Subtotal					1,452	1,320	2,666	2,428
Pulaski - Grade	1,155	35 50	82.5 81.0	1.682 1.526	616 308	616 308	1,036 470	1,036 470
Subtotal					924	924	1,506	1,506
TOTAL LINE	23,595				11,848	11,383	21,230	20,316
Jackson Park Service *Open Deck, Solid Web Girders*								
Englewood Service - 61st St.	990	50 100	81.0 78.5	1.526 1.289	594 594	594 594	906 766	906 766
Total Structure	990				1,188	1,188	1,672	1,672
Open Deck, Lattice Web Girders								
61st St. - Cottage Grove	3,960	20 25 75	84.5 83.5 79.5	1.907 1.791 1.380	1,265 317 238	288 238 238	2,412 568 328	549 426 328
Subtotal					1,820	764	3,308	1,303
Cottage Grove - University	1,930	20	84.5	1.907	897	129	1,711	246
University - Jackson Park	1,475	20	84.5	1.907	444	37	847	71
Total Structure	7,365				3,161	930	5,866	1,620
TOTAL LINE	8,355				4,349	2,118	7,538	3,292
Englewood Service *Open Deck, Solid Web Girders*								
S. Hermitage - S. Ashland	825	15 30	85.5 83.0	2.027 1.736	331 248	248 165	671 431	503 286
Subtotal					579	413	1,102	799
S. Ashland - Racine	2,130	20 25 30 40	84.5 83.5 83.0 82.0	1.907 1.791 1.736 1.628	107 960 216 214	107 960 160 214	204 1,719 375 348	204 1,719 278 348
Subtotal					1,497	1,441	2,646	2,549
Racine - S. Halsted	1,980	15 25 40 50 60 100	85.5 83.5 82.0 81.0 80.5 78.5	2.027 1.791 1.628 1.526 1.476 1.289	968 484 88 264 88 132	352 308 88 220 88 132	1,962 869 143 403 130 170	714 552 143 336 130 170
Subtotal					2,024	1,188	3,677	2,045

TABLE D-5. CTA NOISE IMPACT CALCULATIONS (CONT.)

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit Ldn (dB)	W (Ldn)	Impacted Population (P)		Sound Level Weighted Population (LWP)	
					Residential & Commercial	Residential Only	Residential & Commercial	Residential Only
Englewood Service (Cont.)								
S. Halsted - S. Harvard	2,640	15	85.5	2.027	818	527	1,058	1,068
		25	83.5	1.791	176	176	315	315
		50	81.0	1.526	117	117	179	179
		100	78.5	1.289	466	252	601	325
		150	72.0	0.788	235	235	185	185
Subtotal					1,812	1,307	2,938	2,072
S. Harvard - Wentworth	3,920	15	85.5	2.027	609	609	1,234	1,234
		20	84.5	1.907	522	522	995	995
		30	83.0	1.736	174	174	302	302
		40	82.0	1.628	174	174	283	283
Subtotal					1,479	1,479	2,814	2,814
TOTAL LINE	11,495				7,391	5,828	13,177	10,279
Ravenswood Service Open Deck, Solid Web Girders								
Main Line - Southport	2,475	12	86.5	2.154	495	396	1,066	853
		15	85.5	2.027	495	495	1,003	1,003
		25	83.5	1.791	198	198	355	355
		30	83.0	1.736	198	198	344	344
		35	82.5	1.682	495	495	833	833
		50	81.0	1.526	297	297	453	453
		75	79.5	1.380	198	198	273	273
Subtotal					2,376	2,277	4,327	4,114
Southport - Paulina	1,650	15	85.5	2.027	1,265	825	2,564	1,672
		20	84.5	1.907	110	110	210	210
		30	83.0	1.736	220	220	382	382
Subtotal					1,595	1,155	3,156	2,264
Paulina - Addison	2,145	15	85.5	2.027	455	364	922	338
		20	84.5	1.907	182	182	347	347
		30	83.0	1.736	364	364	632	632
		40	82.0	1.628	91	---	148	---
		50	81.0	1.526	182	182	278	278
Subtotal					1,274	1,092	2,327	1,995
Addison - Irving Park	2,145	15	85.5	2.027	344	344	697	697
		25	83.5	1.791	172	172	308	308
		30	83.0	1.736	344	344	597	597
		50	81.0	1.526	245	245	374	374
		75	79.5	1.380	123	123	170	170
Subtotal					1,228	1,228	2,146	2,146
Irving Park - Montrose	2,145	15	85.5	2.027	344	344	697	697
		25	83.5	1.791	172	172	308	308
		30	83.0	1.736	344	344	597	597
		50	81.0	1.526	344	344	525	525
Subtotal					1,204	1,204	2,127	2,127
Montrose - Damen	2,475	15	85.5	2.027	496	397	1,005	805
		20	84.5	1.907	199	199	379	379
		30	83.0	1.736	199	199	345	345
		50	81.0	1.526	793	793	1,210	1,210
Subtotal					1,687	1,588	2,939	2,739
Damen - Western	2,145	15	85.5	2.027	342	---	693	---
		20	84.5	1.907	171	171	326	326
		30	83.0	1.736	342	342	594	594
		50	81.0	1.526	855	855	1,305	1,305
Subtotal					1,710	1,368	2,918	2,225
Western - Grade	750	25	83.5	1.791	150	150	269	269
		40	82.0	1.628	150	150	244	244
		50	81.0	1.526	300	300	458	458
Subtotal					600	600	971	971
TOTAL LINE	15,600				11,674	10,512	20,911	18,580

TABLE D-5. CTA NOISE IMPACT CALCULATIONS (CONT.)

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit Ldn (dB)	W (L_{dn})	Impacted Population (P)		Sound Level Weighted Population (LWP)	
					Residential & Commercial	Residential Only	Residential & Commercial	Residential Only
Loop								
Open Deck, Lattice Web Girders								
N. Mainline - Clark/Lake	730	30	83.0	1.736	4,745	---	8,237	---
		100	78.5	1.289	1	---	1	---
Subtotal					4,746	---	8,238	---
Clark/Lake - State/Lake	862	30	83.0	1.736	3,276	---	5,687	---
State/Lake - Randolf/Wabash	929	30	83.0	1.736	620	---	1,076	---
		35	82.5	1.682	1,796	---	3,021	---
		40	82.0	1.628	681	---	1,109	---
Subtotal					3,097	---	5,206	---
Randolf/Wabash - Madison/Wabash	862	40	82.0	1.628	4,827	---	7,858	---
Madison/Wabash - Adams/Wabash	1,060	40	82.0	1.628	5,936	2,120	9,664	3,451
Adams/Wabash - LaSalle/VanBuren	2,435	25	83.5	1.791	4,843	417	8,674	747
		30	83.0	1.736	1,227	---	2,130	---
		40	82.0	1.628	2,895	---	4,713	---
		50	81.0	1.526	1,043	1,043	1,592	1,592
Subtotal					10,008	1,460	17,109	2,339
LaSalle/VanBuren - Quincy/Wells	1,194	25	83.5	1.791	3,725	---	6,671	---
		30	83.0	1.736	1,337	---	2,321	---
		35	82.5	1.682	955	---	1,606	---
Subtotal					6,017	---	10,598	---
Quincy/Wells - Madison/Wells	1,224	25	83.5	1.791	1,530	734	2,740	1,315
		40	82.0	1.628	1,224	---	1,993	---
		100	78.5	1.289	979	---	1,262	---
Subtotal					3,733	734	5,995	1,315
Madison/Wells - Randolf/Wells	1,060	25	83.5	1.791	3,710	---	6,645	---
Randolf/Wells - N. Mainline	529	25	83.5	1.791	313	---	568	---
		150	77.0	1.159	2,116	---	2,452	---
Subtotal					2,429	---	3,020	---
TOTAL LINE	10,385				47,779	4,314	80,020	7,105
North Side Mainline								
Open Deck, Solid Web Girders								
Lawrence - Wilson	1,080	5	89.5	2.571	216	---	555	---
		25	83.5	1.791	324	324	580	580
Subtotal					540	324	1,135	580
Wilson - Sheridan	4,785	20	84.5	1.907	766	766	1,460	1,461
		25	83.5	1.791	574	574	1,028	1,028
		30	83.0	1.736	1,148	574	1,993	996
		40	82.0	1.628	383	383	624	624
		45	81.5	1.577	574	574	905	905
		50	81.0	1.526	574	---	876	---
Subtotal					4,019	2,871	6,886	5,014
Sheridan - Addison	1,980	15	85.5	2.027	594	---	1,204	---
		20	84.5	1.907	495	495	944	944
		30	83.0	1.736	297	297	516	516
		40	82.0	1.628	198	198	322	322
		50	81.0	1.526	297	297	453	453
Subtotal					1,381	1,287	3,439	2,235

TABLE D-5. CTA NOISE IMPACT CALCULATIONS (CONT.)

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit Ldn (dB)	W (Ldn)	Impacted Population (P)		Sound Level Weighted Population (LWP)	
					Residential & Commercial	Residential Only	Residential & Commercial	Residential Only
North Side Mainline (Cont.)								
Addison - Belmont	2,145	15	85.5	2.027	1,599	1,285	3,241	2,605
		20	84.5	1.907	172	172	328	328
		25	83.5	1.791	343	343	614	614
		50	81.0	1.526	257	257	392	392
Subtotal					2,371	2,057	4,575	3,939
Belmont - Wellington	1,155	15	85.5	2.027	116	116	235	235
		20	84.5	1.907	173	173	330	330
		25	83.5	1.791	232	232	416	416
		30	83.0	1.736	116	116	201	201
		50	81.0	1.526	173	173	264	264
Subtotal					810	810	1,446	1,446
Wellington - Diversery	1,155	15	85.5	2.027	404	404	819	819
		20	84.5	1.907	173	173	330	330
		25	83.5	1.791	116	116	208	208
		50	81.0	1.526	173	173	264	264
		75	79.5	1.380	173	173	239	239
Subtotal					1,039	1,039	1,860	1,860
Diversery - Fullerton	2,310	15	85.5	2.027	405	405	821	821
		20	84.5	1.907	348	116	664	221
		25	83.5	1.791	174	---	312	---
		50	81.0	1.526	232	232	354	354
Subtotal					1,159	753	2,151	1,396
Fullerton - Armitage	2,310	10	87.0	2.219	694	694	1,540	1,540
		20	84.5	1.907	347	231	662	441
		25	83.5	1.791	347	347	621	621
		50	81.0	1.526	347	347	530	530
Subtotal					1,735	1,619	3,353	3,132
Armitage - Sedgwick	4,895	15	85.5	2.027	1,276	1,126	2,586	2,282
		25	83.5	1.791	450	300	806	537
		40	82.0	1.628	300	300	488	488
		50	81.0	1.526	226	226	345	345
		75	79.5	1.380	150	---	207	---
		100	78.5	1.289	301	301	388	388
		200	76.0	1.078	1,204	1,204	1,298	1,298
Subtotal					3,907	3,457	6,118	5,338
Sedgwick - Chicago	4,620	15	85.5	2.027	246	246	499	499
		20	84.5	1.907	554	492	1,056	938
		25	83.5	1.791	185	185	331	331
		40	82.0	1.628	738	738	1,201	1,201
		50	81.0	1.526	185	185	282	282
		75	79.5	1.380	185	185	255	255
		100	78.5	1.289	246	246	317	317
		200	76.0	1.078	739	739	797	797
Subtotal					3,078	3,016	4,738	4,620
Total Structure	26,435				20,539	17,233	35,701	29,560
Open Deck, Lattice Web Girders								
Chicago - Merchandise Mart	2,410	20	84.5	1.907	160	107	305	204
		25	83.5	1.791	374	321	670	575
Subtotal					534	428	975	779
Merchandise Mart - Loop	990	25	83.5	1.791	4,224	---	7,565	---
Total Structure	3,400				4,758	428	8,540	779
TOTAL LINE	29,835				25,297	17,661	44,241	30,339

TABLE D-5. CTA NOISE IMPACT CALCULATIONS (CONT.)

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit Ldn (dB)	W (Ldn)	Impacted Population (P) Residential & Commercial	Impacted Population (P) Residential Only	Sound Level Weighted Population (LWP) Residential & Commercial	Sound Level Weighted Population (LWP) Residential Only
South Side Mainline Open Deck, Solid Web Girders								
Dan Ryan - Tech 35	7,095	25	83.5	1.791	473	---	847	---
		75	79.5	1.380	189	---	261	---
Subtotal					662	---	1,108	---
Tech 35 - Indiana	3,630	20	84.5	1.907	322	322	614	614
		30	83.0	1.736	161	161	280	280
		50	81.0	1.526	242	242	369	369
		75	79.5	1.380	564	564	778	778
		100	78.5	1.289	242	242	312	312
Subtotal					1,531	1,531	2,353	2,353
Indiana - 43rd St.	2,310	20	84.5	1.907	346	346	660	660
		30	83.0	1.736	231	231	401	401
		75	79.5	1.380	1,038	1,038	1,432	1,432
		100	78.5	1.289	577	577	744	744
Subtotal					2,192	2,192	3,237	3,237
43rd St. - 47th St.	2,310	30	83.0	1.736	346	346	601	601
		75	79.5	1.380	2,192	2,192	3,025	3,025
Subtotal					2,538	2,538	3,626	3,626
47th St. - 51st St.	2,145	50	81.0	1.526	1,284	1,284	1,959	1,959
		75	79.5	1.380	321	321	443	443
		100	78.5	1.289	321	321	414	414
		125	77.5	1.202	321	321	386	386
Subtotal					2,247	2,247	3,202	3,202
51st St. - 55th St.	2,145	50	81.0	1.526	858	858	1,309	1,309
		75	79.5	1.380	858	858	1,184	1,184
Subtotal					1,716	1,716	2,493	2,493
55th St. - 58th St.	1,650	5	89.5	2.571	83	---	213	---
		50	81.0	1.526	248	248	378	378
		100	78.5	1.289	496	496	639	639
		125	77.5	1.202	248	248	298	298
Subtotal					1,075	992	1,528	1,315
58th St. - Englewood Service	660	30	83.0	1.736	396	396	687	687
		75	79.5	1.380	396	396	546	546
Subtotal					792	792	1,233	1,233
TOTAL LINE	21,945				12,753	12,008	18,780	17,459

APPENDIX E: DADE COUNTY METRORAIL INVENTORY

E.1 Elevated Structure – Description

The Metropolitan Dade County Rapid Transit System (Metrorail) is currently in the design stage. When complete, it will consist of 34 km (21 miles) of elevated concrete guideway serving the Miami, Florida metropolitan area (see Fig. E-1). Although designs for the elevated structure have not been finalized at this writing, basic design features include a concrete deck with or without noise barriers, as an integral part of a double tee or box section girder, supported by single column concrete piers (see Fig. E.2).

E.2 Noise Estimation

The estimation of L_{dn} for the Dade transit system elevated structures is based on a preliminary acoustical analysis of the system [*E.1*]. Maximum A-weighted noise levels for a two-car train were taken from the vehicle specifications, which indicate the noise level at 15 m (50 ft) from at-grade ballast-and-tie track, as a function of speed as follows (see Fig. E-3):

$$L_{max}\ (50\ ft) = 36 + 25 \log (v), \qquad (E.1)$$

where L_{max} (15 m) is the maximum (peak) noise level, in dBA, at 50 ft distance, and v is the vehicle speed, in mph. If these levels are decreased by 2 dB to correct them to a single car, and if they are increased by 5 dB to account for operation on elevated guideway one obtains:

$$L_{max}\ (50\ ft) = 39 + 25 \log (v)\ . \qquad (E.2)$$

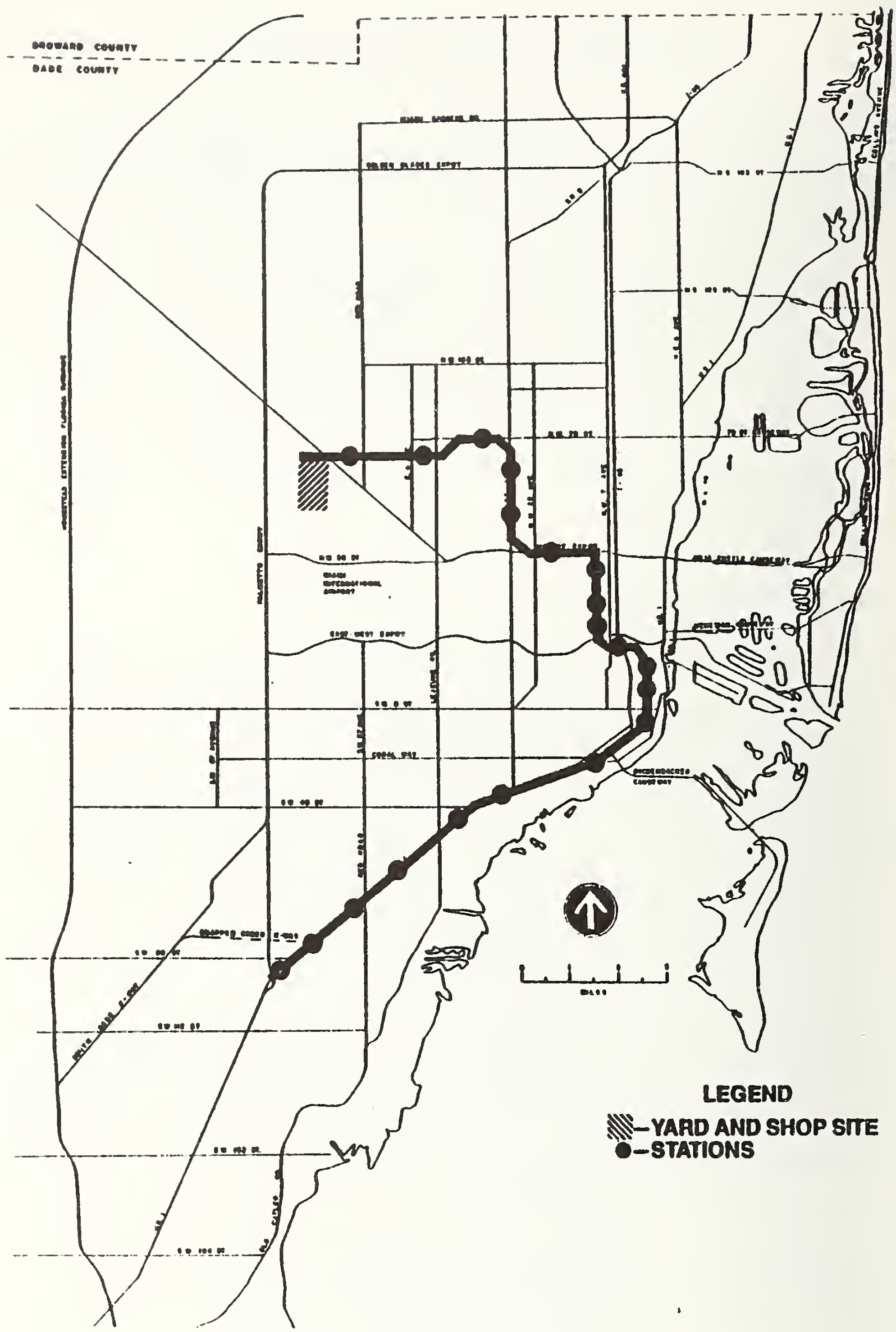


FIGURE E-1. PROPOSED METROPOLITAN DADE COUNTY RAPID TRANSIT SYSTEM

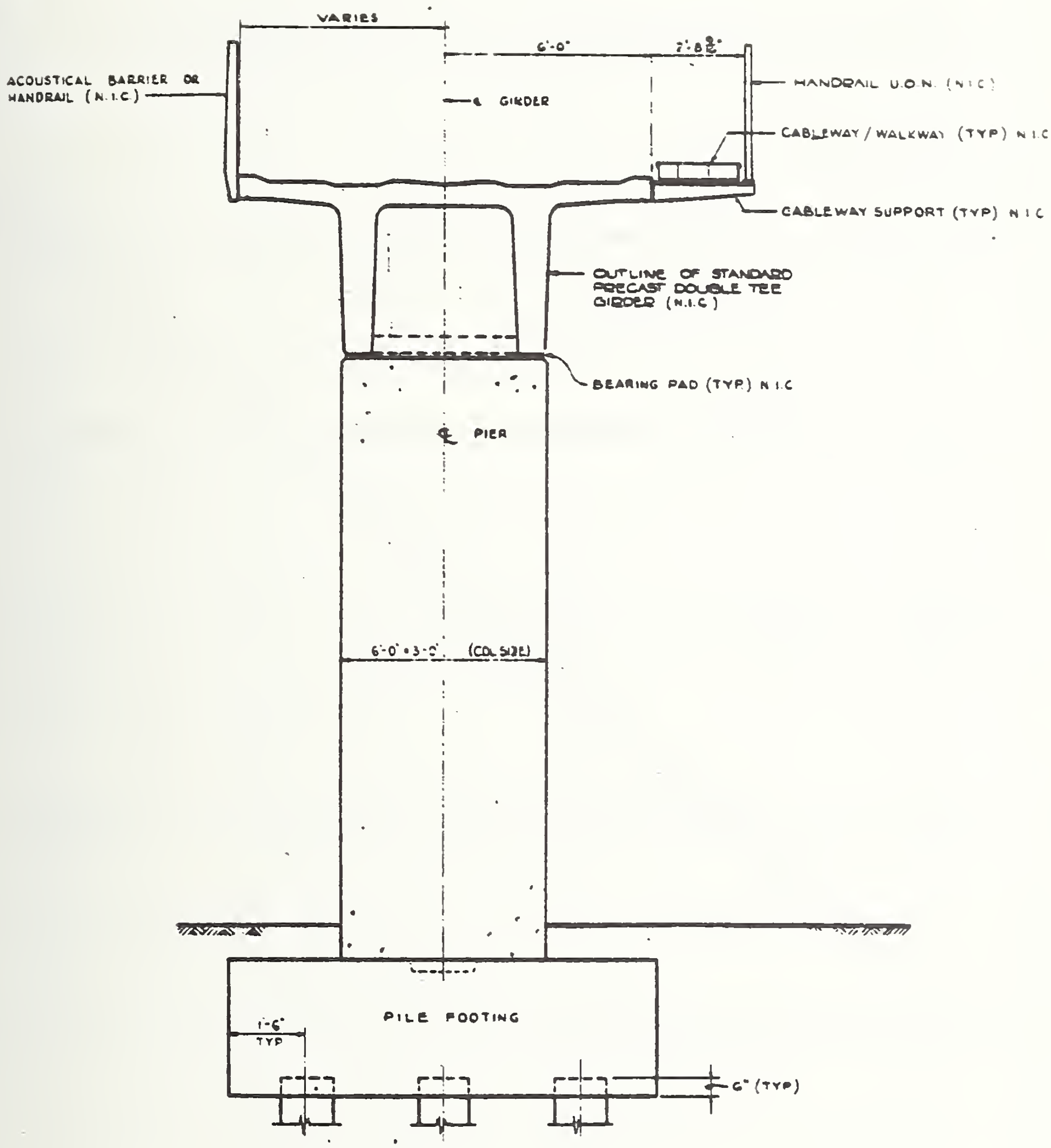


FIGURE E-2. TYPICAL SECTION OF PROPOSED DADE METRORAIL ELEVATED STRUCTURE

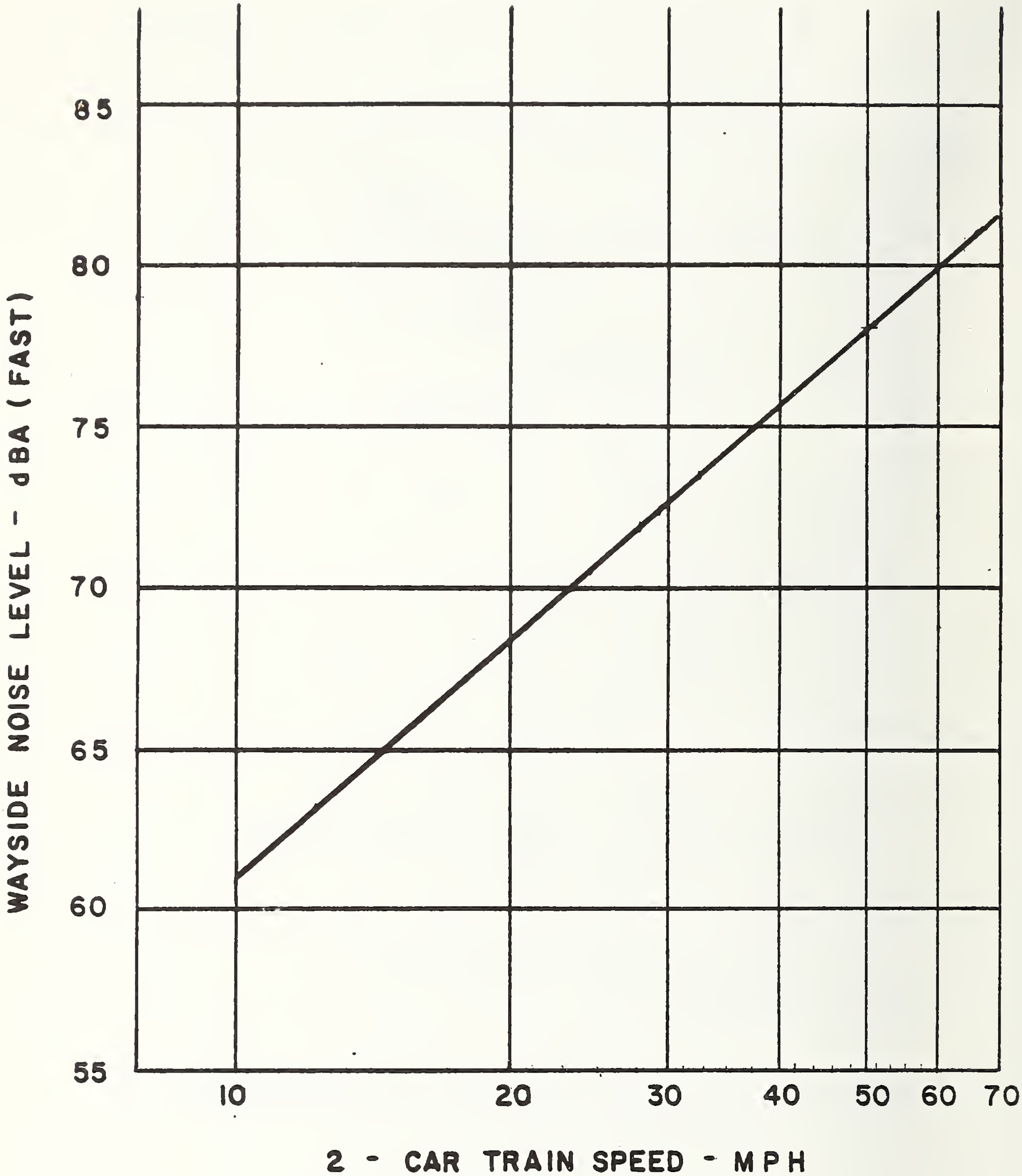


FIGURE E-3. MAXIMUM WAYSIDE NOISE LEVEL LIMITS AT 50 FT FROM TRACK CENTERLINE

The conversion from maximum sound level, L_{max}, to the hourly equivalent noise level, $L_{eq}(hr)$, is accomplished by averaging train passby energy over a 1-hr period, according to the following equation [*E.2*]:

$$L_{eq}(hr) = 41 + 15 \log(v) + 10 \log(n) - 10 \log(d) , \qquad (E.3)$$

where $L_{eq}(hr)$ is the hourly equivalent noise level, in dBA; v is the vehicle speed, in mph; n is the number of transit car passbys per hr; and d is the distance from track centerline, in ft.

The number of train passbys, number of cars in each train, and time of day of each train are obtained from the System Specifications [*E.3*] (see Table E-1). Using this schedule data, the L_{eq} is calculated for each hour of the day. These results are then averaged, with a 10 dB penalty added to nighttime (10:00 p.m. to 7:00 a.m.) operations to obtain the L_{dn} for single track operation:

$$L_{dn} = 71 + 15 \log(v/70) - 10 \log(d/50) , \qquad (E.4)$$

where L_{dn} is the day-night average sound level, in dB; v is the vehicle speed, in mph; and d is the distance to track centerline, in ft. Train speeds along the transit route are obtained from system speed profiles [*E.4*], and northbound and southbound results are logarithmically added to estimate the transit L_{dn} at any given distance from the elevated structure.

TABLE E-1. STAGE 1 SYSTEM — PRELIMINARY TRAIN OPERATIONS SCHEDULE (1985)

STAGE I SYSTEM
PRELIMINARY TRAIN OPERATIONS SCHEDULE
(1985)

WEEKDAY

5:00 A.M. TO 6:00 A.M.	9 FOUR-CAR TRAINS	9 MINUTE HEADWAY
6:00 A.M. TO 7:00 A.M.	9 FOUR-CAR TRAINS 4 SIX-CAR TRAINS	6 MINUTE HEADWAY
7:00 A.M. TO 9:00 A.M.	10 SIX-CAR TRAINS 13 FOUR-CAR TRAINS	3 MINUTE HEADWAY*
9:00 A.M. TO 4:00 P.M.	13 FOUR-CAR TRAINS	6 MINUTE HEADWAY
4:00 P.M. TO 6:00 P.M.	10 SIX-CAR TRAINS 13 FOUR-CAR TRAINS	3 MINUTE HEADWAY*
6:00 P.M. TO 7:00 P.M.	9 FOUR-CAR TRAINS 4 SIX-CAR TRAINS	6 MINUTE HEADWAY
7:00 P.M. TO 9:00 P.M.	9 FOUR-CAR TRAINS	9 MINUTE HEADWAY
9:00 P.M. TO 1:00 A.M.	9 TWO-CAR TRAINS	9 MINUTE HEADWAY

SATURDAY

5:00 A.M. TO 7:00 A.M.	9 TWO-CAR TRAINS	9 MINUTE HEADWAY
7:00 A.M. TO 9:00 A.M.	9 FOUR-CAR TRAINS	9 MINUTE HEADWAY
9:00 A.M. TO 7:00 P.M.	13 SIX-CAR TRAINS	6 MINUTE HEADWAY
7:00 P.M. TO 9:00 P.M.	9 FOUR-CAR TRAINS	9 MINUTE HEADWAY
9:00 P.M. TO 1:00 A.M.	9 TWO-CAR TRAINS	9 MINUTE HEADWAY

SUNDAY

5:00 A.M. TO 8:00 A.M.	9 TWO-CAR TRAINS	9 MINUTE HEADWAY
8:00 A.M. TO 8:00 P.M.	13 FOUR-CAR TRAINS	6 MINUTE HEADWAY
8:00 P.M. TO 1:00 A.M.	9 TWO-CAR TRAINS	9 MINUTE HEADWAY

* DADELAND SOUTH, NORTHSIDE, HIALEAH AND OKEECHOBEE WILL OPERATE AT 6 MIN. TRAIN HEADWAY.

E.3 Fractional Impact Analysis

The fractional impact analysis for the Dade transit system elevated structures is accomplished by the method outlined by Schultz [*E.5*], which involves the following steps:

1. Ambient noise levels are estimated by use of standard noise prediction methods for highways, airports, and railroads, supported by actual noise measurements [*E.1*]. Areas bordering the transit system alignment are divided into ambient L_{dn} regions in 5 dB intervals (e.g., 60-65, 65-70, 70-75, etc.).

2. Transit L_{dn} contour regions are determined in intervals of 5 dB (e.g., 55-60, 60-65, 65-70, etc.); the alignment is divided into segments with constant characteristics of transit noise, ambient noise, and land use.

3. The number of dwelling units is counted for each segment and tabulated according to transit noise level and the differential between transit noise and ambient noise. Residences located in regions where the transit noise is estimated to be more than 5 dB below the ambient noise are eliminated from the analysis.

4. For each system segment, the number of impacted people is estimated by assuming an average of three people per residential unit. The result is then reduced by one-half, as suggested by Schultz [*E.5*], to account for the assumption that only that half of the population that face the tracks are significantly impacted.

5. The Sound Level Weighted Population (LWP) for each route segment is then calculated by multiplying the population by the associated noise weighting function (W) for the median transit L_{dn} in each range. The total LWP is then calculated by summing these results over the entire length of elevated structure.

The results of the fractional impact analysis for the Dade transit system elevated structures are summarized in Table E.2. The estimated number of people expected to be exposed to various levels of elevated structure transit noise is given below:

Transit L_{dn} (dB)	*Impacted Population*
70 to 75	504
65 to 70	5,175
60 to 65	15,829
55 to 60	1,618

Note that the above analysis assumes no special noise controls. It is likely, however, that noise barriers will be incorporated on approximately half of the structures for the Dade system in order to minimize noise impact. It is estimated that the use of barriers that provide a noise reduction of 10 dB would decrease the number of impacted people by a factor of 4 and would reduce the LWP by a factor of 8.

REFERENCES — APPENDIX E

E.1 Hanson, C.E., Eldred, K.M., and Towers, D.A., "Acoustical Criteria Investigations and Analysis for the Metropolitan Dade County Rapid Transit System," BBN Draft Rept. No. 4099 (April 1979).

E.2 U.S. Department of Transportation, "Final Environmental Impact Statement — Orange Line Relocation and Arterial Street Construction (Southwest Corridor Project)," UMTA Project No. MA-23-9007, FHWA Project No. U-393(1), Appendix H (March 1978).

E.3 Kaiser Transit Group, "Metropolitan Dade County Transportation Improvement Program — Stage 1 Rapid Transit System — Draft System Specifications," (March 1978).

E.4 Kaiser Transit Group, "Metropolitan Dade County - Stage I - Rapid Transit System - Dadeland South to Okeechobee Velocity/ Distance Profile Data," (December 1978).

E.5 Schultz, T.J., "Noise Rating Criteria for Elevated Rapid Transit Structures," BBN Rept. No. 3905 (April 1979).

TABLE E-2. METROPOLITAN DADE COUNTY RAPID TRANSIT SYSTEM ELEVATED TRANSIT STRUCTURE NOISE IMPACT SUMMARY

Station	Number of Impacted People	Sound Level Weighted Population
Dadeland South		
Dadeland North	1,108	385
South Miami	1,968	756
University	1,402	514
Douglas Rd.	1,651	579
Coconut Grove	1,406	489
Vizcaya	2,481	930
Brickell	1,833	581
Govt. Center	1,507	488
Washington Hts.	1,304	365
Culmer	837	338
Civic Center	0	0
Santa Clara	0	0
Allapattah	998	401
Earlington Hts.	1,221	468
Brownsville	690	260
M.L. King, Jr. Plaza	591	227
Northside	670	270
Hialeah	2,164	888
Okeechobee	1,295	455
TOTAL (without noise Barriers)	23,126	8,394
(estimated with Barriers)	5,782	1,050

APPENDIX F: MBTA INVENTORY

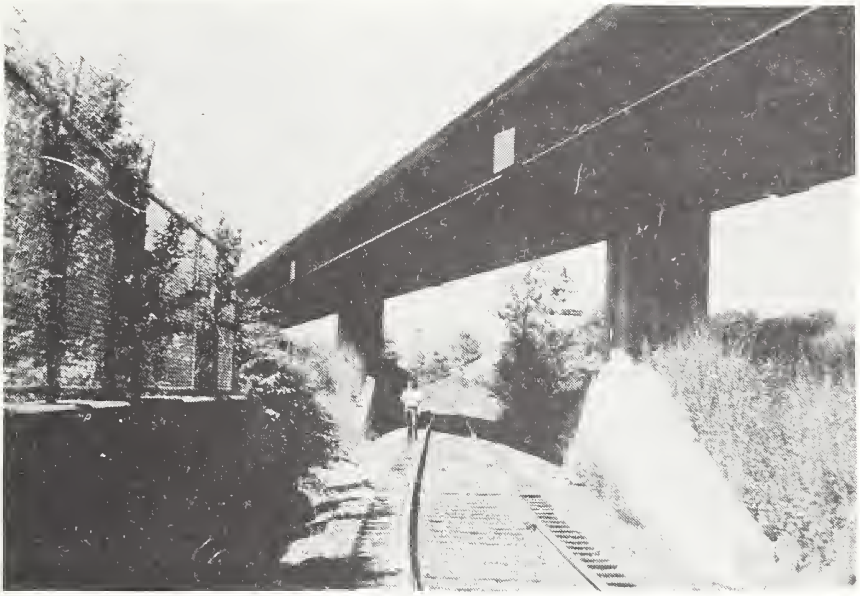
F.1 Elevated Structure Design

The Massachusetts Bay Transportation Authority (MBTA) system, located in the Boston area, currently contains approximately 8.7 km (5.4 miles) of elevated structure on the Red, Green, and Orange Line transit routes. Note that bridges here are not considered elevated transit structures.

The MBTA Red Line route includes about 0.5 km (0.3 miles) of elevated structure (excluding the Longfellow Bridge). The Longfellow Bridge approach over Charles St. Circle, in the Beacon Hill section of Boston, comprises 0.2 km (0.1 miles) of elevated structure (see Fig. F-1). The substructure of this segment consists of one concrete abutment, one rectangular concrete pier, two twin-column steel plate girder bents, seven piers of double transverse steel plate girders supported on reinforced concrete stems, and a granite block abutment. The superstructure includes three spans consisting of four built-up steel plate stringers, 1.5 m (5 ft) deep, supporting a reinforced concrete deck. The remaining spans consist of three through-plate girders, 2.4 m (8 ft) deep, with concrete-encased 30.5 cm (12 in.) floor beams and 25.4 cm (10 in.) stringers supporting the reinforced concrete deck. Tracks rest on ties on ballast. Additional steelwork supports the Charles St. Station structure. The remaining 0.3 km (0.2 miles) of Red Line structure is located on the Quincy Line in Dorchester. The Savin Hill Flyover, shown in Fig. F-2, consists of a concrete deck supported on longitudinal steel plate stringers, approximately 1.5 m (5 ft) in depth, which in turn are supported on concrete piers. The track is directly fastened to the concrete deck.

Note: Refer to text for structure location and description

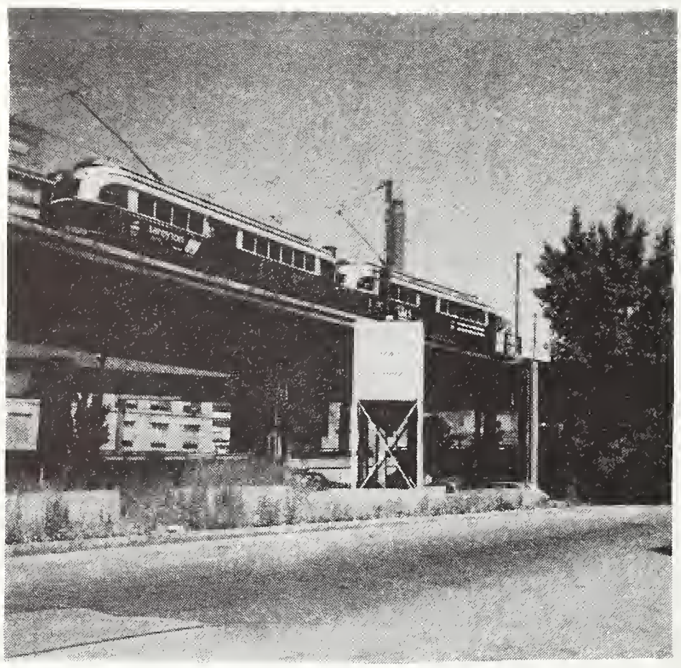
FIGURE F-1. RED LINE ELEVATED STRUCTURE AT CHARLES ST. CIRCLE



Note: Refer to text for structure location and description

FIGURE F-2. RED LINE (QUINCY BRANCH) ELEVATED STRUCTURE AT SAVIN HILL

The MBTA Green Line operates on an elevated structure for about 1.1 km (0.7 miles) in the vicinity of the North Station, Science Park, and Lechmere stations (excluding the viaduct over the Charles River). The structure, shown in Fig. F-3, consists primarily of two-column steel bents supporting four to eight longitudinal steel plate stringers, 1.5 m (5 ft) deep for each span, which in turn carry a concrete deck, stone ballast, ties, and rails. A system of cross framing stiffens the longitudinal girders. A 0.2 km (0.1 mile) segment of the structure, between the north portal and North Station is of open deck construction with wood ties mounted directly on 1.2 m (4 ft)-deep steel plate stringers.



Note: Refer to text for structure location and description

FIGURE F-3. GREEN LINE ELEVATED STRUCTURE BETWEEN NORTH STATION AND SCIENCE PARK

The MBTA Orange Line operates on elevated steel structure for approximately 7.1 km (4.4 miles) between the Essex Street and Forest Hills stations. Steel bents support longitudinal braced steel stringers; wood ties are mounted directly on these stringers. About 3.4 km (2.1 miles) of the structure includes lattice web girder stringers (see Fig. F-4), while about 3.7 km (2.3 miles) of the structure includes solid web girder stringers (see Fig. F-5). Use of the Orange Line elevated structure is likely to be discontinued in the near future, as a result of the Boston Southwest Corridor relocation project.

F.2 Noise Estimation

The estimation of L_{dn} for the MBTA system elevated structures is based on field noise measurements conducted specifically for this project during July 1979. These measurements were performed at representative locations along each transit line for each type of elevated structure. The measurement microphone was positioned at distances ranging between 4.6 and 23 m (15 and 75 ft) from the centerline of the near track of the structure, at approximately rail height. At each location, approximately 12 train passbys were monitored, including passbys on the near and the far track; speeds were measured, and the number and type of cars were noted for each train. Train passbys were measured using a BBN Model 614 Portable Noise Monitor to obtain the A-weighted maximum level (L_{max}) and the single event noise exposure level (SENEL). Tape recordings were also made for selected train passbys by use of a Kudelski Nagra IV-SJ tape recorder; the recorded data were subsequently reduced in the laboratory, in order to provide spectra.

FIGURE F-4. ORANGE LINE ELEVATED STRUCTURE WITH LATTICE WEB GIRDERS

Note: For Figures F-4 and F-5, refer to text for structure location and description

FIGURE F-5. ORANGE LINE ELEVATED STRUCTURE WITH SOLID WEB GIRDERS

The data for both near and far track train passbys on the various elevated structures were averaged logarithmically to obtain average L_{max} and SENEL results for each measurement site. Attempts at data normalization for train speed and length generally did not result in a reduction in data scatter; thus raw data averages were used to represent typical noise levels. The measurement results are summarized in Table F-1. Figures F-6 through F-10 show the noise measurement locations.

The day-night average sound level, L_{dn} was calculated by summing the sound energy of all train passbys, with a 10-dB penalty added to nighttime (10 p.m. to 7 a.m.) operations, and averaging the result over a 24-hr period. Thus:

$$L_{dn}(d) = \text{SENEL}(d, 1 \text{ car}) + 10 \log(n_{day} + 10n_{night}) - 49.4, \quad \text{(F.1)}$$

where L_{dn} is the day-night average sound level, in dB, at a distance d. SENEL(d, 1 car) is the single event noise exposure level for a single car passby at a distance d, in dBA. n_{day} is the number of transit cars in daytime (7 a.m. to 10 p.m.), and n_{night} is the number of transit cars at nighttime (10 p.m. to 7 a.m.).

The SENEL for one car is obtained from the measurement results, assuming that SENEL varies as 10 log (no. of cars). The number of car passbys was obtained from MBTA schedule data [*F.1*]. The L_{dn} for distances other than the measurement distance is calculated assuming that L_{dn} varies as 10 log (1/distance). Near and far track L_{dn} components are combined to obtain the total L_{dn}. The results are given in Fig. F-11 for each type of elevated structure. Because the noise levels for train passbys on the lattice web and solid web stringer type Orange Line

TABLE F-1. MBTA SYSTEM ELEVATED STRUCTURE NOISE MEASUREMENT SUMMARY

Site No.	Elevated Line	Structure Type* and Location	Track	Avg. No. of Cars	Avg. Train Speed, km/h (mph)	Measurement Distance, m (ft)	Avg. L_{max} (dBA)	Avg. SENEL (dBA)
1	Red Line	Steel/concrete structure, concrete deck & ballast track. Charles St. Circle	Near	2	40 (25)	7.5 (25)	95	99
			Far	2	45 (28)	12 (40)	90	94
2	Green Line	Steel girders, concrete deck & ballasted track. Between North Sta. & Science Park Station	Near	2	32 (20)	4.6 (15)	94	92
			Far	2	29 (18)	8.4 (27.5)	83	87
3	Red Line (Quincy Branch)	Steel girders, concrete deck & unballasted track. Dorchester (Savin Hill Flyover)	Near	4	39 (24)	23 (75)	86	93
			Far	4	39 (24)	27 (90)	83	90
4	Orange Line	Steel, solid web girder stringers & open (wood tie) deck. Washington St. and Brinton St.	Near	4	58 (36)	6.7 (22)	105	110
			Far	4	50 (31)	10 (34)	98	104
5	Orange Line	Steel, lattice web girder stringers & open (wood tie) deck. Washington St. between W. Brookline and W. Newton Streets	Near	4	56 (35)	14 (46)	103	109
			Far	4	53 (33)	21 (70)	96	102

*See text for details.

FIGURE F-6. MEASUREMENT SITE NO. 1

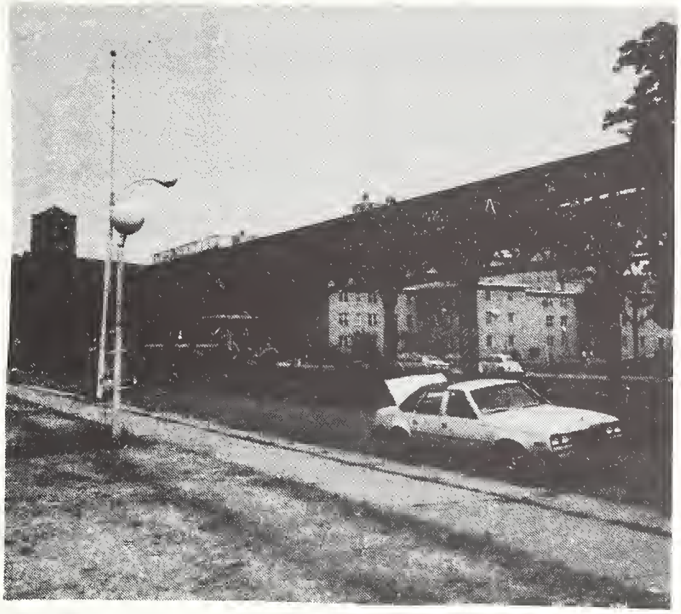
Note: For Figures F-6 and F-7, refer to text for structure location and description

FIGURE F-7. MEASUREMENT SITE NO. 2

FIGURE F-8. MEASUREMENT SITE NO. 3

Note: For Figures F-8 and F-9, refer to text for structure location and description

FIGURE F-9. MEASUREMENT SITE NO. 4



Note: Refer to text for structure location and description

FIGURE F-10. MEASUREMENT SITE NO. 5

structures are not significantly different (in view of the data scatter), these results are averaged for application to fractional impact analysis of the entire Orange Line.

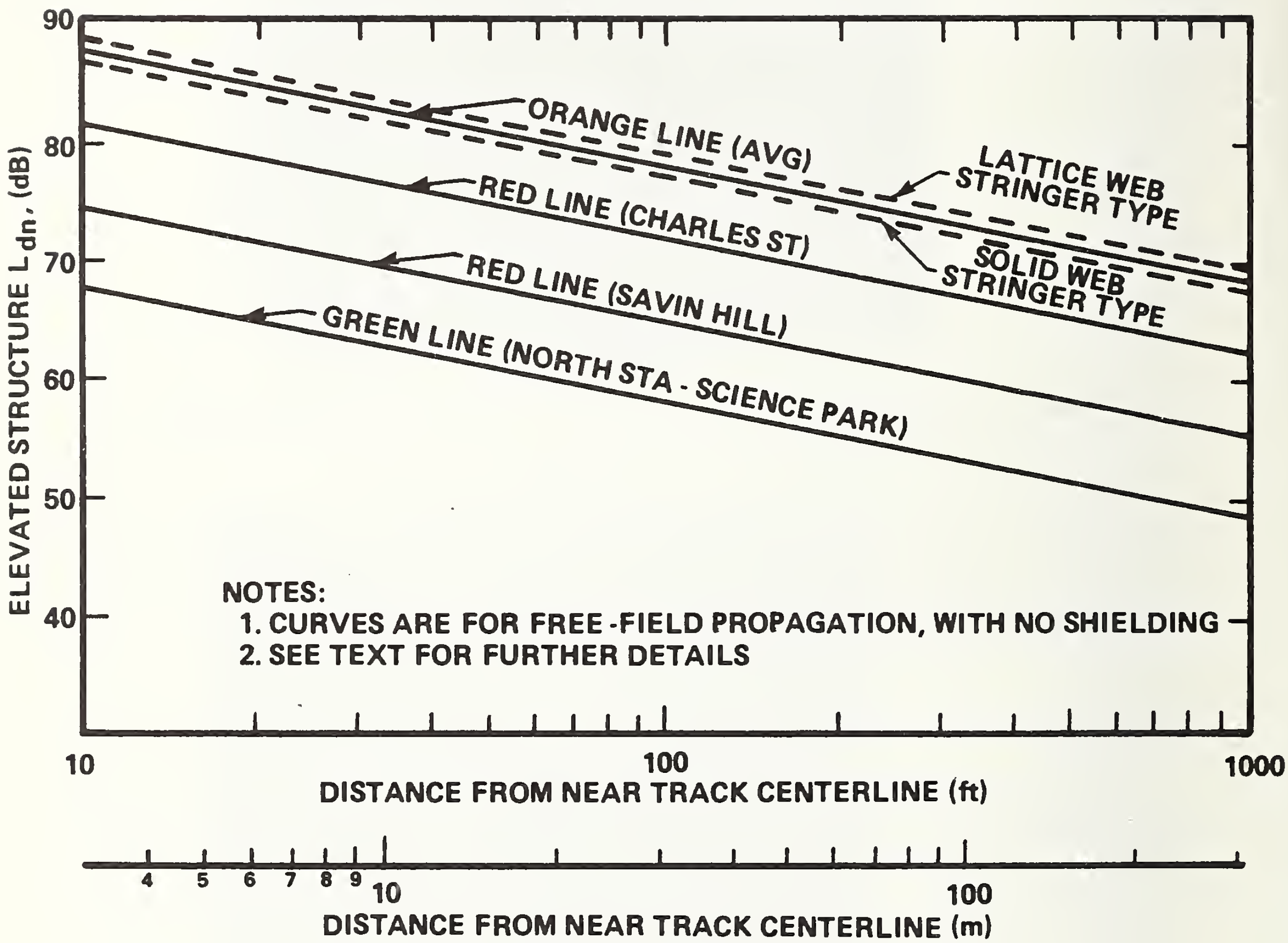
F.3 Fractional Impact Analysis

The fractional impact analysis was accomplished by the method outlined by Schultz [*F.2*], using the following steps:

1. Ambient noise levels (without MBTA) are estimated, based on population density data [*F.3*], using the relation

$$L_{dn} = 9 \log(\rho) + 30 \text{ dB}, \tag{F.2}$$

where ρ = population density (people per square mile).



Note: Refer to text for structure location and description

FIGURE F-11. MBTA ELEVATED STRUCTURE TRANSIT NOISE ESTIMATION

Equation (F.2) was developed on the basis of Boston noise data taken from an EPA study [*F.4*], which suggests that Boston tends to be noisier than the average U.S. city.

2. The transit L_{dn} component is estimated, as outlined in the previous section, at distances corresponding to residential locations.

3. For the Red and Green Line elevated structures, the analysis includes all nonshielded residences within about 30 m (100 ft) of the structure. A count of these residences was obtained from a BBN inventory survey. Other residential locations are not considered in the analysis since the transit noise is estimated to be more than 5 dB below the ambient noise at these other locations. An average of three people are assumed to occupy each residential unit, and the impacted population is reduced by one-half, as suggested by Schultz [*F.2*], to account for the assumption that only that half of the people that face the tracks are significantly impacted.

4. For the Orange Line elevated structures, where higher transit noise levels exist and more "open" building siting is found, noise impact extends beyond the first row of buildings. Therefore, a different analysis approach is used here. Transit L_{dn} contour distances are determined in 5-dB intervals, extending between the average nearest residential distance to the distance at which the transit L_{dn} is 5 dB below the ambient L_{dn}. The nearest residences are generally located at either 15 or 60 m (50 or 200 ft) from the

structure, as found from BBN observations and previous studies [*F.5*]. Shielding adjustments for noise propagation beyond the first row of buildings are made by taking the first row to provide a noise reduction of 4.5 dB, while every subsequent row provides an additional 1.5-dB reduction, up to a maximum of 10 dB. This shielding estimate is typical for highway noise [*F.6*]. A representative building row spacing of 30 m (100 ft) is used for the propagation estimate. From population and land use data [*F.3*], the number of impacted people is estimated by multiplying the population density by the residential land area within each transit L_{dn} range. This result is then reduced by one-half, as suggested by Schultz [*F.2*], to account for the assumption that only that half of the people that face the tracks are significantly impacted.

5. The Sound Level Weighted Population (LWP) for each route segment is calculated by multiplying the impacted population by the noise weighting function (W) for the associated transit L_{dn}. The total LWP is then calculated for each elevated line, for each structure type, and for the entire system by summing the LWPs for the appropriate route segments.

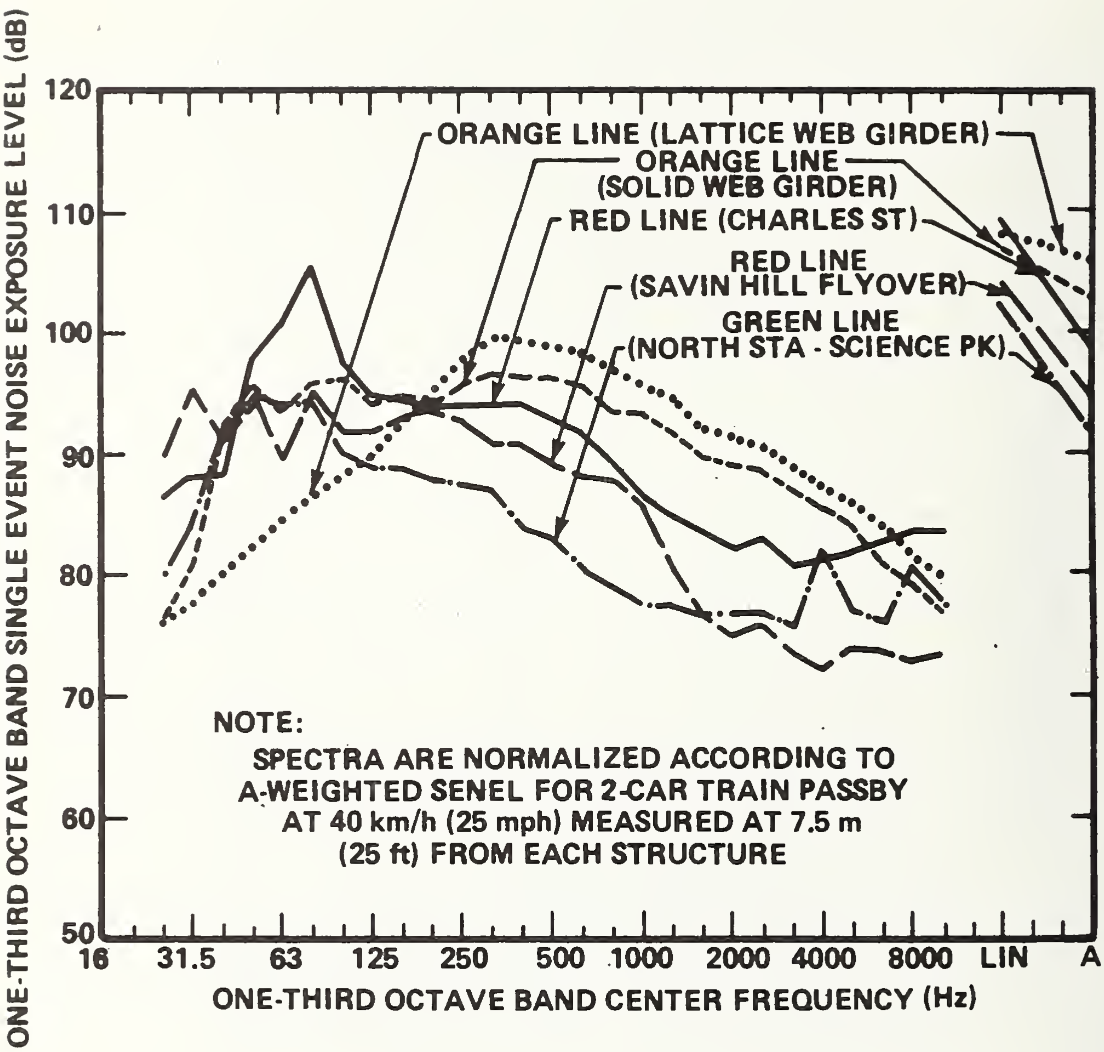
The results of the fractional impact analysis for the MBTA system elevated structures are summarized in Table F-2. Note that the short open-deck segment of the Green Line Structure is not included in this analysis; the noise impact from this structure is not significant because the ambient levels at this location are high, as compared to the transit noise.

Figure F-12 illustrates typical noise spectra for train passbys on the various types of elevated structure.

TABLE F-2. MBTA TRANSIT SYSTEM ELEVATED STRUCTURE FRACTIONAL IMPACT ANALYSIS SUMMARY

Elevated Line	Structure Type*	No. of People Exposed to Elevated Structure Noise Within Various Ranges of L_{dn}, in dB						Sound Level Weighted Population (LWP)
		60-65	65-70	70-75	75-80	80-85	TOTAL	
Red Line	Steel/concrete structure, concrete deck and ballast track	–	–	30	15	12	57	61
Green Line	Steel structure, concrete deck and ballast track	239	–	–	–	–	239	64
Red Line (Quincy Branch)	Concrete structure, steel stringers and unballasted track	–	60	–	–	–	60	30
Orange Line	Steel structure, solid web girder stringers and open tie deck	267	500	356	152	27	1302	855
Orange Line	Steel structure, lattice web girder stringers and open tie deck	33	134	166	72	7	412	310
Red & Green Lines	Concrete deck, tie and ballast	239	–	30	15	12	296	125
Red Line (Quincy)	Concrete deck, direct fixation	–	60	–	–	–	60	30
Orange Line	Open deck, solid web girders	267	500	356	152	27	1302	855
Orange Line	Open deck, lattice web girders	33	134	166	72	7	412	310
ALL LINES	ALL TYPES	539	694	552	239	46	2070	1320

*See text for details.



Note: Refer to text for structure location and description

FIGURE F-12. MBTA ELEVATED TRANSIT STRUCTURE RELATIVE NOISE SPECTRA

REFERENCES – APPENDIX F

F.1 Stavisky, R.D. (MBTA), letter to C.W. Menge (BBN), (2 August 1979).

F.2 Schultz, T.J., "Noise Rating Criteria for Elevated Rapid Transit Structures," BBN Report No. 3905 (April 1979).

F.3 Chisholm, G. *et al.*, "National Assessment of Urban Rail Noise," U.S. Department of Transportation, Urban Mass Transportation Administration, Report No. UMTA-MA-06-0099-79-2 (March 1979).

F.4 U.S. Environmental Protection Agency, "Population Distribution of the United States as a Function of Outdoor Noise Level," Report No. EPA-550/9-74-009A (June 1974).

F.5 Kurzweil, L.G. *et al.*, "Noise Assessment and Abatement in Rapid Transit Systems – Report on the MBTA Pilot Study," U.S. Department of Transportation, Urban Mass Transportation Administration, Report No. UMTA-MA-06-0025-74-8 (September 1974).

F.6 Kugler, B.A. and Piersol, A.G., "Highway Noise – A Field Evaluation of Traffic Noise Reduction Measurement," National Cooperative Highway Research Program Report 144 (1973).

APPENDIX G: NYCTA INVENTORY

G.1 Elevated Structure Description

The New York City Transit Authority (NYCTA) system contains approximately 95.8 km (59.5 miles) of elevated structure (see Fig. G-1). The system includes four general types of elevated structures as described below.

1. *Open Deck Steel Structure with Solid Web Girder Stringers:* This is the predominant structure type, comprising about 84.5 km (52.5 miles) of the system. This type of structure consists of steel bents supporting longitudinal plate girders 1.2 or 1.5 m (4 or 5 ft) in depth. Track support consists of wood ties fastened directly to the stringers. On approximately 300 m (1000 ft) of the Broadway — 7th Avenue elevated line there are resilient pads between the rail and the ties. This small segment is not considered separately in the present impact evaluation.

2. *Open Deck Steel Structure with Lattice Web Girder Stringers:* This type of structure comprises only about 0.8 km (0.5 miles) and is located between the Avenue X and Van Siclen stations on the Coney Island elevated line. Track support consists of wood ties fastened directly to the stringers.

3. *Reinforced Concrete Viaduct:* This type of structure comprises approximately 8.9 km (5.5 miles) of the Rockaway and Flushing elevated lines. Track support consists of wood ties with stone ballast.

4. *Concrete-Encased Steel:* This type of structure comprises about 1.6 km (1 mile) of the Coney Island elevated line in the vicinity of the Smith and 9th Street station. The structure

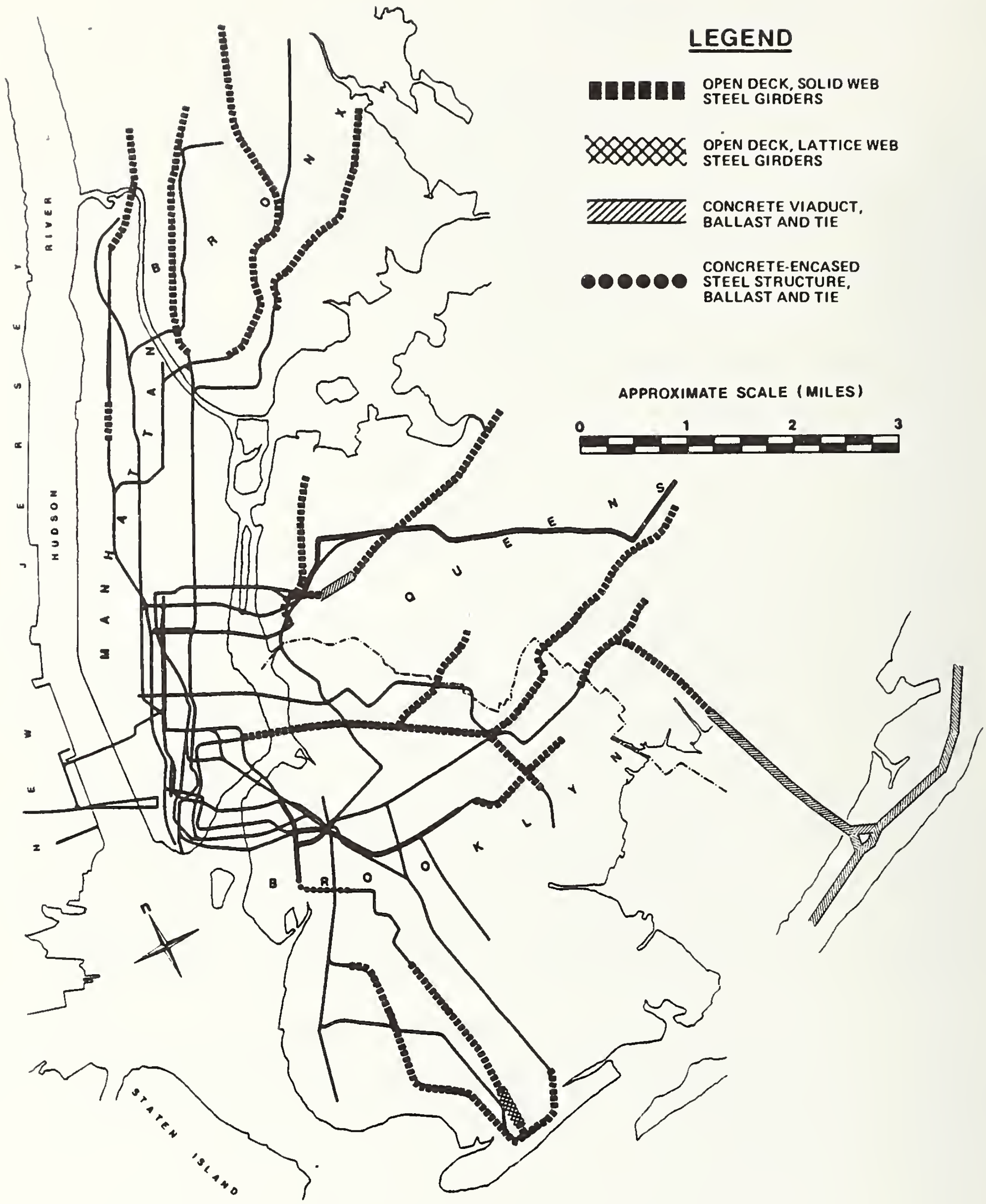


FIGURE G-1. NYCTA SYSTEM ELEVATED STRUCTURES

includes barrier walls along the edge of the deck, at 1 m (3 ft) above the top-of-rail height. Track support consists primarily of wood ties with stone ballast. A 183 to 244 m (600 to 800 ft) segment of the structure includes track support consisting of resilient fasteners with concrete invert and bolted rail. This small segment is not included as a special case for the purposes of the impact elevation.

G.2 Noise Estimation

The estimation of L_{dn} for the NYCTA elevated structures is based on field noise measurements conducted by BBN during the week of 18 June 1979. These measurements were collected by tape recording train passbys at ten locations, including each type of elevated structure. The measurement microphone was positioned at distances ranging between 3.8 and 9.1 m (12.5 and 30 ft) from the centerline of the near track of the structure, at approximately rail height. Physical constraints at the measurement locations necessitated deviation from the usual 7.5 m (25 ft) measurement distance in some cases. At each location, between 6 and 22 recordings were made, including both near and far track train passbys; speeds were clocked using a stopwatch, and the number and type of cars were noted. The recorded data were subsequently reduced in the laboratory, using a BBN Model 614 Portable Noise Monitor to obtain the A-weighted maximum level (L_{max}) and the single event noise exposure level (SENEL) for each train passby. These data were then normalized to average conditions, i.e., a 7-car train at 40 km/h (25 mph), measured at 7.5 m (25 ft), using the following relations:

a. Speed Adjustment: $L_{max} \propto 30 \log (\text{speed})$

$\text{SENEL} \propto 20 \log (\text{speed})$

b. Train Length Adjustment: L_{max} constant

SENEL $\propto$ 10 log (no. of cars)

c. Distance Adjustment: $L_{max} \propto$ 20 log (1/distance<7.5 m),

$L_{max} \propto$ 10 log (1/distance, 7.5 to 30 m)

SENEL $\propto$ 10 log (1/distance).

The normalized data were then averaged logarithmically to obtain average L_{max} and SENEL results for each measurement site. These results are summarized in Table G.1. (Note that average normalized L_{max} results are provided for near track train passbys only.) Photographs of the elevated structure noise measurement sites are provided in Figs. G.2 through G.11.

Tape recordings of selected train passbys were reduced in the laboratory using a real-time analyzer to provide spectral data. Figure G.12 illustrates typical noise spectra for train passbys on the four basic types of NYCTA structures.

Out of the ten measurement sites, six were along elevated structures with solid web girder stringers, the predominant structure type. Three of these sites (1, 2, and 8) were in areas with "open" surroundings, i.e., with no reflecting surfaces nearby. The other three sites (6, 9, and 10) were in so-called "canyon" areas, i.e., areas with tall buildings located close to the structure along both sides.

The stringer depth for the structures measured was 1.5 m (5 ft), except for one of the "open" measurement sites that included a structure with a stringer depth of 1.2 m (4 ft). Based on noise radiating area, one might expect 1.2 m (4 ft)

TABLE G-1. NEW YORK CITY TRANSIT SYSTEM ELEVATED STRUCTURE NOISE MEASUREMENT SUMMARY

Site	Elevated Line	Location Description	Structure Type	Acoustical Environment	Average Normalized Near Track L_{max}* (dBA)	Average Normalized SENEL* (dBA)
1	Flushing Line	Roosevelt Ave. & 50th St., Queens (Outbound Side)	Steel with 1.5 m (5 ft) solid web girders, open deck (wood tie)	"Open"	104 (1 passby)	106 (6 passbys)
2	Lefferts Blvd. Line	Liberty Ave. & 48th St., Queens (Inbound Side)	Steel with 1.5 m (5 ft) solid web girders, open deck (wood tie)	"Open"	99 (7 passbys)	105 (10 passbys)
3	Rockaway Line	Edgemere Ave. between 48 & 49th St., Queens (Outbound Side)	Reinforced concrete viaduct, wood tie & ballast, bolted rail	"Open"	91 (3 passbys)	97 (6 passbys)
4	Rockaway Line	Rockaway Beach Blvd. & B 102nd St., Queens (Outbound Side)	Reinforced concrete viaduct, wood tie & ballast, bolted rail	"Open"	90 (3 passbys)	96 (7 passbys)
5	Coney Island-Culver Line	Shell Rd. & Cobek Ct., Brooklyn (Outbound Side)	Steel with lattice web girders, open deck (wood tie)	"Open"	96 (7 passbys)	104 (15 passbys)
6	West End Line	New Utrecht Ave. between 52 & 53 St., Brooklyn (Inbound Side)	Steel with 1.5 m (5 ft) solid web girders, open deck (wood tie)	"Canyon" with 24 m (80 ft) street width	104 (6 passbys)	111 (12 passbys)
7	Coney Island-Culver Line	Smith St. & Luquer St., Brooklyn (Inbound Side)	Concrete-encased steel, wood tie & ballast, bolted rail, 1 m (3 ft) high barrier wall	"Open"	85 (9 passbys)	91 (16 passbys)
8	Broadway-Jamaica Line	Broadway between Schaefer St. & Decatur St., Brooklyn (Inbound Side)	Steel with 1.2 m (4 ft) solid web girders, open deck (wood tie)	"Open"	100 (5 passbys)	106 (11 passbys)
9	Broadway-Jamaica Line	Fulton St. between Shepherd Ave. & Highland Pl., Brooklyn (Outbound Side)	Steel with 1.5 m (5 ft) solid web girders, open deck (wood tie)	"Canyon" with 20 m (65 ft) street width	98 (6 passbys)	110 (12 passbys)
10	Flushing Line	Roosevelt Ave. between 54 & 55th St., Queens (Outbound Side)	Steel with 1.5 m (5 ft) solid web girders, open deck (wood tie)	"Canyon" with 20 m (65 ft) street width	97 (4 passbys)	106 (22 passbys)

*L_{max} or SENEL at 7.5 m (25 ft) for a 7-car train passby at 40 km/h (25 mph).

Note: See Table G-1 and text for site location and structure description details

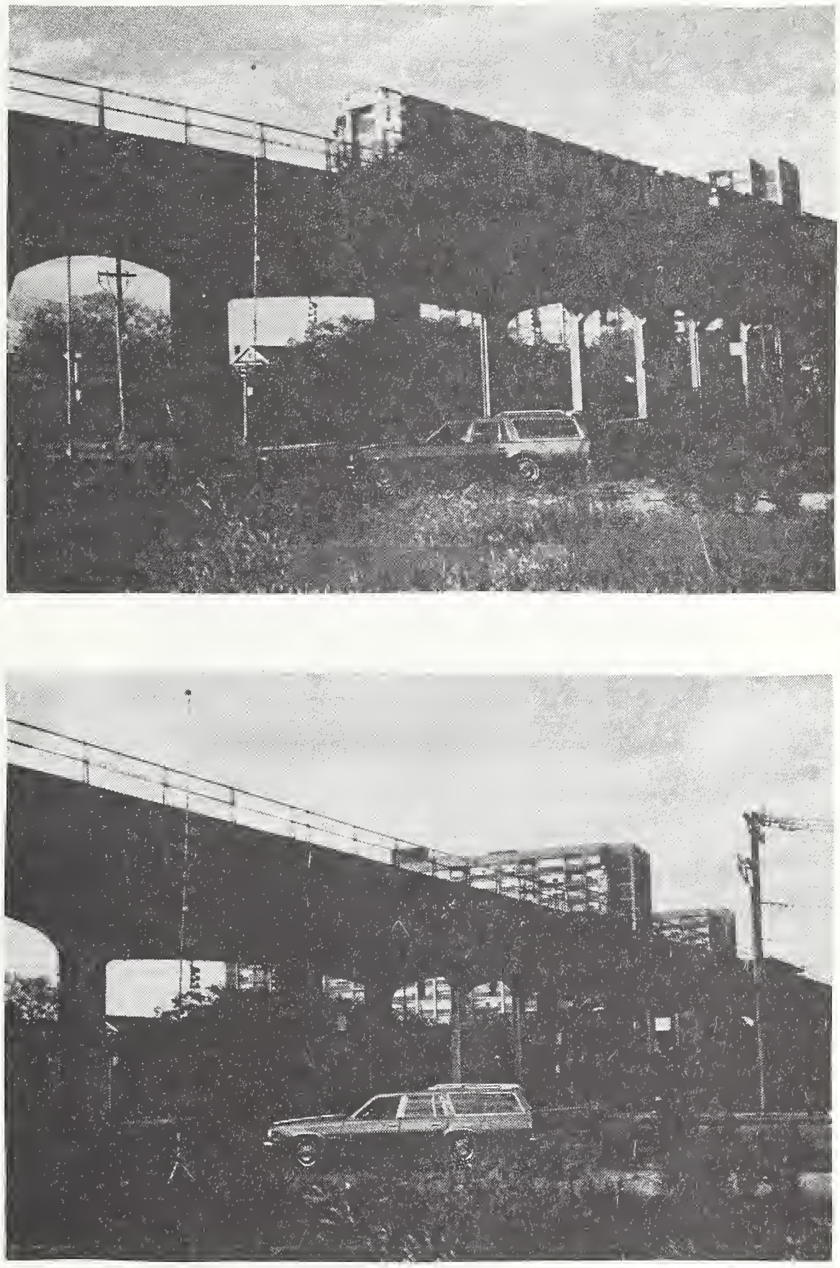
FIGURE G-2. MEASUREMENT SITE NO. 1

Note: See Table G-1 for site location and structure description details

FIGURE G-3. MEASUREMENT SITE NO. 2

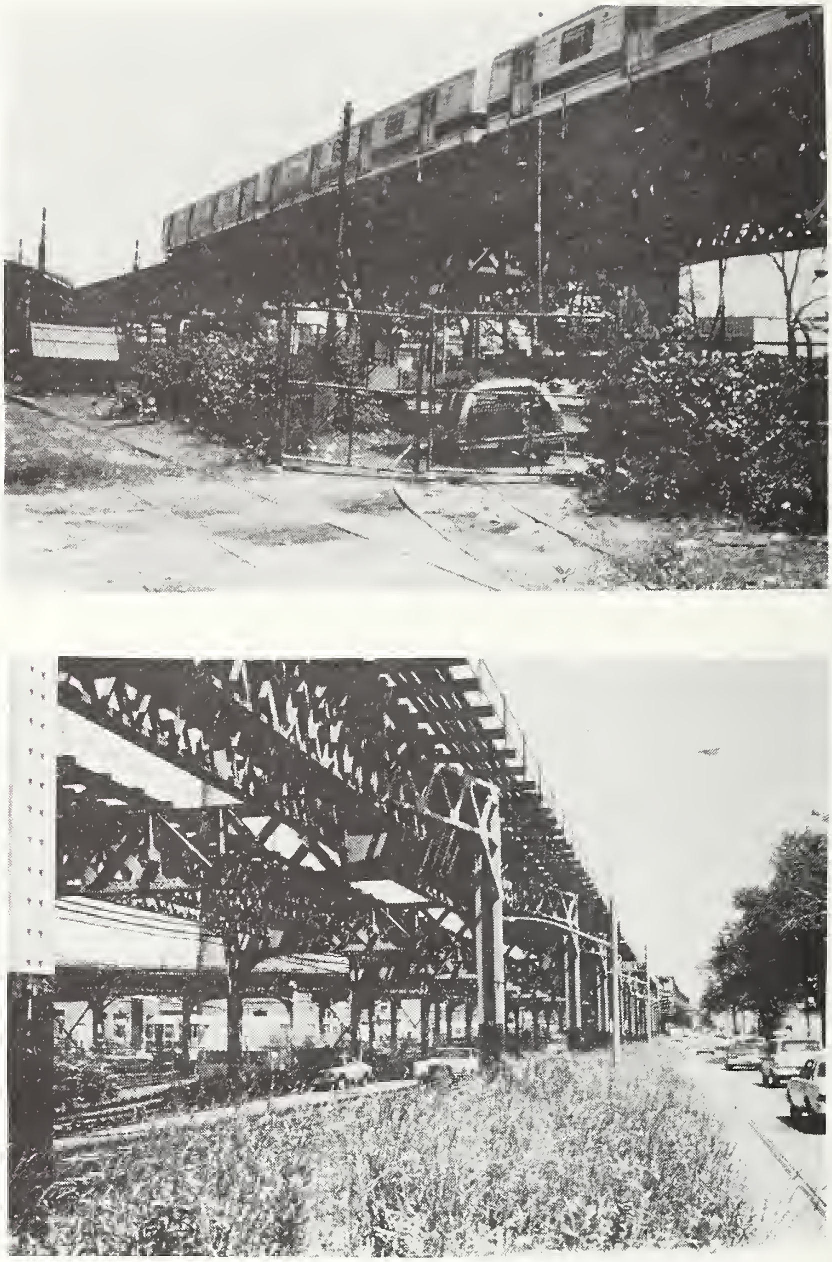
Note: See Table G-1 for site location and structure description details

FIGURE G-4. MEASUREMENT SITE NO. 3



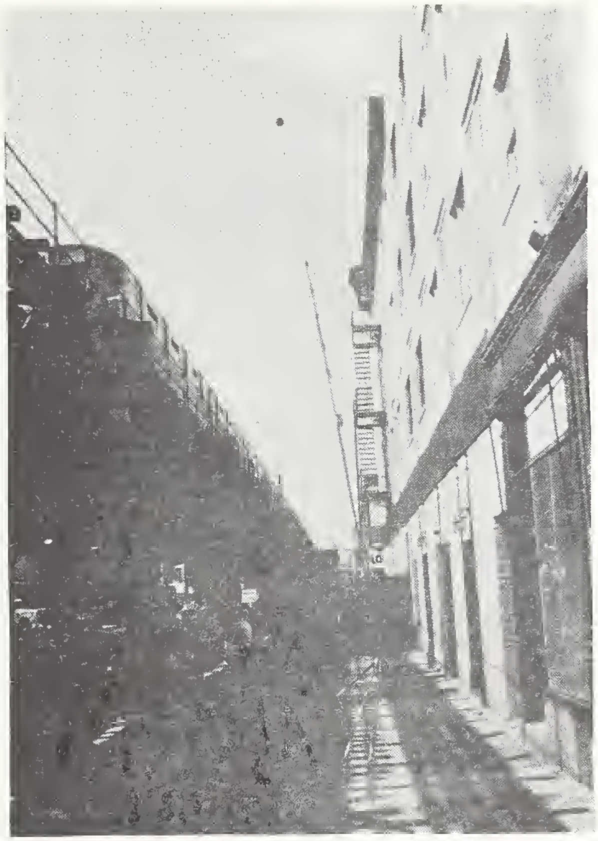
Note: See Table G-1 and text for site location and structure description details

FIGURE G-5. MEASUREMENT SITE NO. 4



Note: See Table G-1 and text for site location and structure description details

FIGURE G-6. MEASUREMENT SITE NO. 5

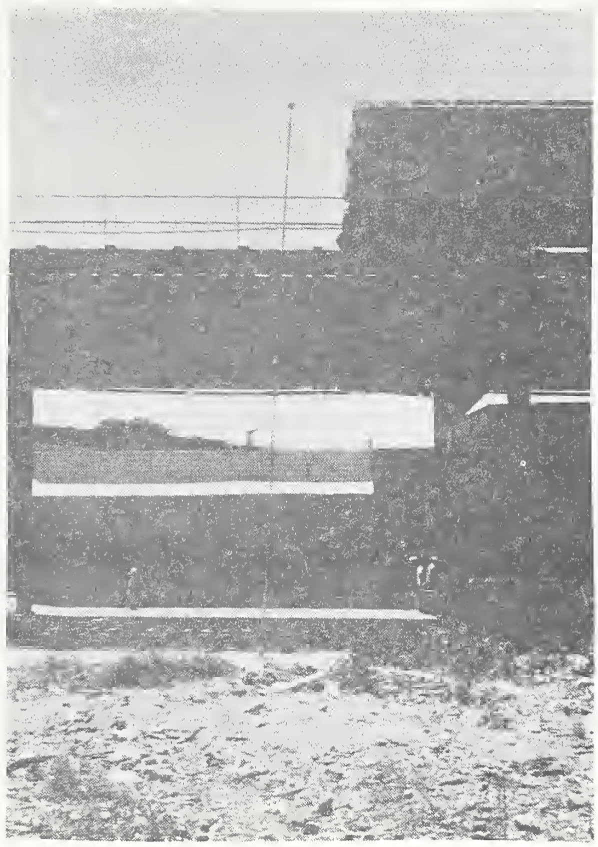


Note: See Table G-1 and text for site location and structure description details

FIGURE G-7. MEASUREMENT SITE NO. 6

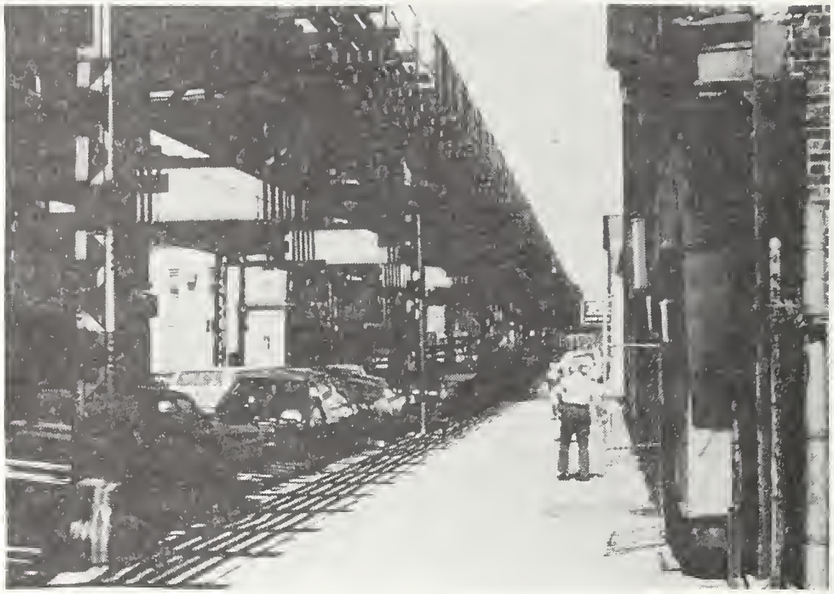
Note: See Table G-1 and text for site location and structure description details

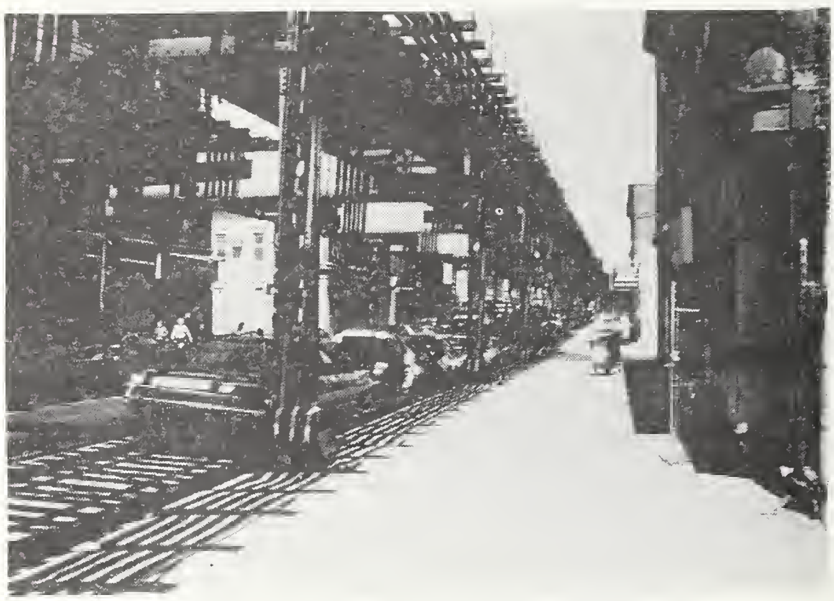
FIGURE G-8. MEASUREMENT SITE NO. 7



Note: See Table G-1 and text for site location and structure description details

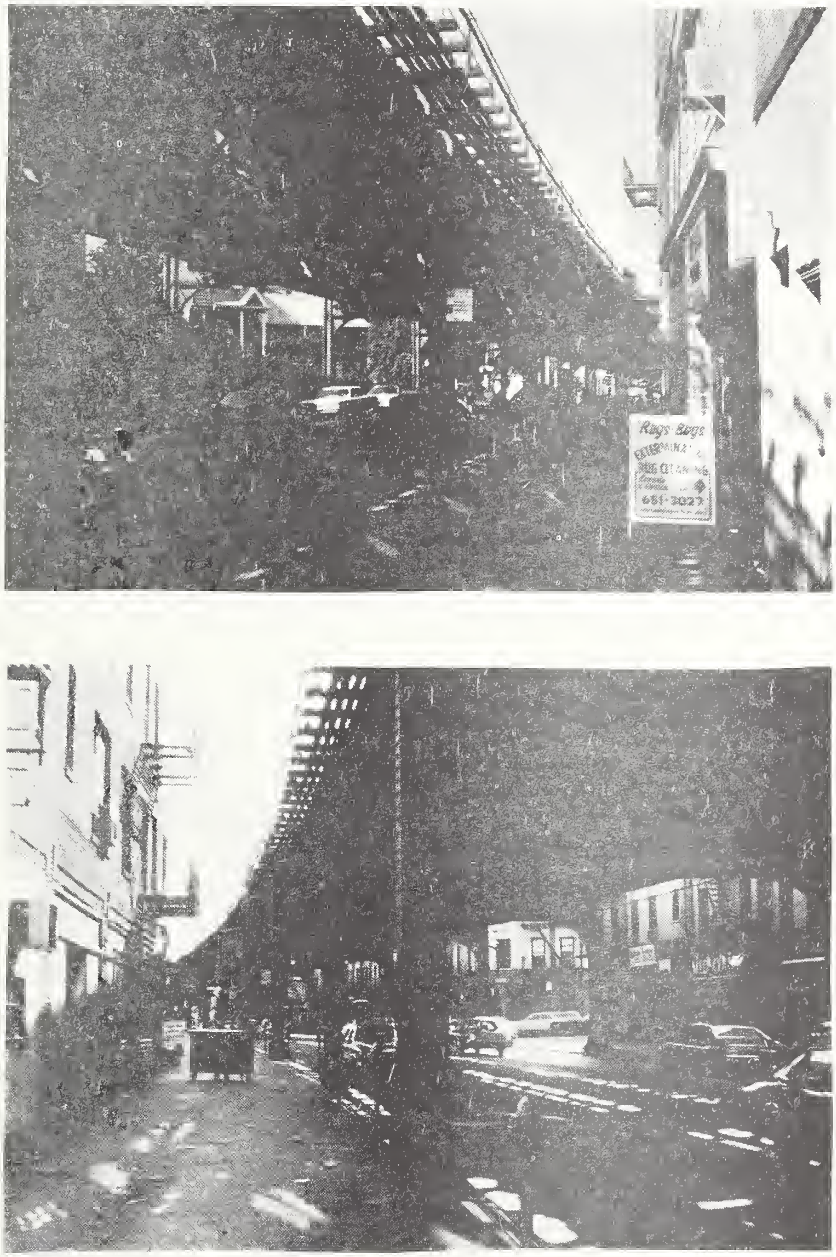
FIGURE G-9. MEASUREMENT SITE NO. 8





Note: See Table G-1 and text for site location and structure description details

FIGURE G-10. MEASUREMENT SITE NO. 9



Note: See Table G-1 and text for site location and structure description details

FIGURE G-11. MEASUREMENT SITE NO. 10

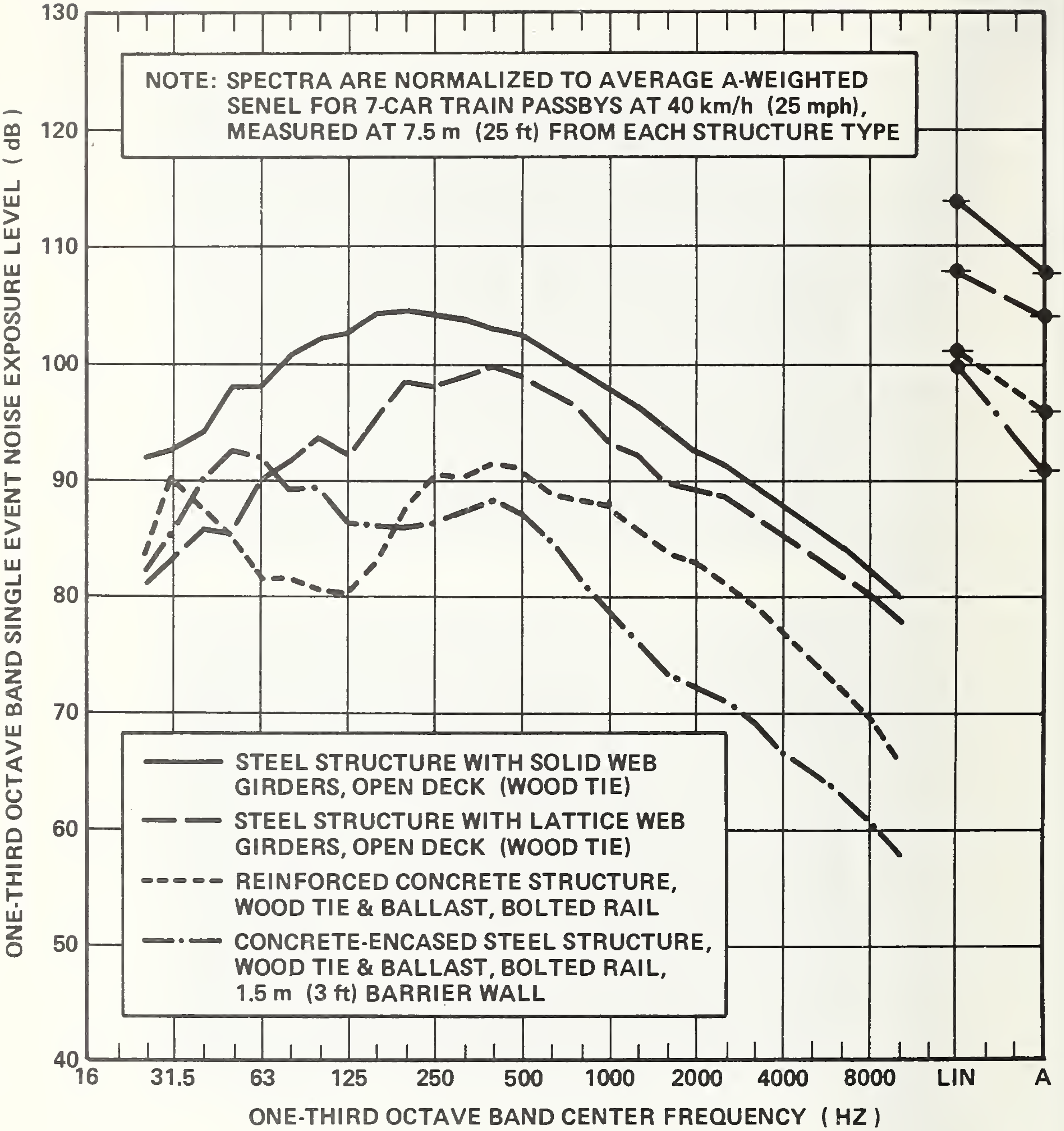


FIGURE G-12. NYCTA ELEVATED TRANSIT STRUCTURE RELATIVE NOISE SPECTRA

stringers to radiate 1 dB less acoustic energy than 1.5 m (5 ft) stringers. However, average SENEL results for the structure with 1.2 m (4 ft) stringers (Site 8) are not significantly different from the results for the structures with 1.5 m (5 ft) stringers measured in an "open" environment. Considering the scatter of the data, it does not seem justifiable to make a distinction between these stringer constructions in terms of noise emission.

In terms of environmental factors, the "canyon" type measurement site SENEL results are about 3 dB greater than those for the "open" type sites, on the average. However, note that for Site 10, with a street width between buildings of 20 m (65 ft), the average SENEL is on the same order as that for the "open" sites. Note also that the average SENEL for Site 6, with a 24 m (80 ft) street width, is higher than the average SENEL measured at Sites 9 and 10, with street widths of 20 m (65 ft). Theoretically, one would expect more reverberation and higher SENEL values at the narrower canyon sites. These discrepancies suggest that the results are highly dependent on the details of the particular measurement site chosen. Thus, it is not considered justifiable to differentiate between "open" and "canyon" type sites, based on the scatter in the measurement data. It is proposed that all six measurements be averaged to obtain a normalized SENEL of 108 dBA for 7-car train passbys at 40 km/h (25 mph) measured at 7.5 m (25 ft) from elevated steel structures with solid web girder stringers.

Measurements for the three remaining structural types were conducted in "open" acoustical environments since this environment was observed to be typical for these structures. Data for Site 5 indicate an average normalized SENEL of 104 dBA for

train passbys on the elevated steel structure segment with lattice web girder stringers. Data for Sites 3 and 4 indicate an average normalized SENEL of 96 dBA for train passbys on reinforced concrete viaduct structures. Similarly, measurements at Site 7 suggest an average normalized train passby SENEL of 91 dBA for the concrete-encased steel elevated structure.

In addition to the above analysis, near track and far track SENEL data were normalized for speed and train length in order to investigate propagation effects. Data at Sites 2, 3, 5, and 10 displayed the theoretical free-field 10 log (distance) dependence for acoustic line sources. Data at Sites 1, 4, 6, 7, and 8 showed average excess attenuations ranging between 1 and 4 dB for the far track cases, possibly due to shielding effects. Data at Site 9 indicated less than free-field attenuation, possibly due to reverberant effects. These results suggest that the propagation effects are strongly dependent on location-related details. Thus, deviation from the free-field line source propagation assumption is not considered justifiable for the far track data. In summary, the average normalized SENEL values for New York City Transit train passbys on elevated structures are as follows:

1.	Steel with Solid Web Girder Stringers:	108 dBA	SENEL at 7.5 m (25 ft), 40 km/h (25 mph), 7-car train
2.	Steel with Lattice Web Girder Stringers:	104 dBA	
3.	Reinforced Concrete Viaduct:	96 dBA	
4.	Concrete-Encased Steel:	91 dBA	

Analysis of L_{max} results for near track train passbys (i.e., without structural shielding effects) yields the following results:

1. Steel with Solid Web Girder Stringers:	101 dBA	L_{max} at 7.5 m (25 ft), 40 km/h (25 mph)
2. Steel with Lattice Web Girder Stringers:	96 dBA	
3. Reinforced Concrete Viaduct:	90 dBA	
4. Concrete-Encased Steel:	85 dBA	

These results indicate that the L_{max} for train passbys on NYCTA elevated structures is typically 6 to 8 dB below the SENEL.

The day-night average sound level, L_{dn}, is calculated by summing the sound energy of all train passbys, with a 10-dB penalty added to nighttime (10 p.m. to 7 a.m.) operations, and averaging the result over a 24-hr period. The L_{dn} is computed as follows:

$$L_{dn}(7.5\text{ m}) = \text{SENEL (norm.)} + 10 \log [N_{day}+10N_{night}] - 49.4, \quad \text{(G.1)}$$

where L_{dn} (7.5 m) is the day-night average sound level, in dB, at a distance of 7.5 m (25 ft); SENEL(norm.) is the single event noise exposure level for a typical train passby at 7.5 m (25 ft), in dbA; N_{day} is the number of train passbys between 7 a.m. and 10 p.m.; and N_{night} is the number of train passbys between 10 p.m. and 7 a.m.

Information supplied by the New York City Transit Authority [*G.1*] indicates that train length ranges from 4 to 10 cars, and that the average speed is 40 km/h (25 mph); L_{dn} is therefore

calculated assuming 7-car trains moving at 40 km/h (25 mph). Train frequency data are based on information received from NYCTA for the IRT No. 2 Line, which is assumed typical of all lines [*G.2*]. This schedule lists 96 daytime and 41 nighttime train passbys in each direction. Based on these numbers, the single-track (one-direction) L_{dn} is calculated for each structure type using Eq. G.1. The results are provided below:

1.	Steel with Solid Web Girder Stringers:	86 dB	L_{dn} at 7.5 m (25 ft), 40 km/h (25 mph), 7-car trains (one direction).
2.	Steel with Lattice Web Girder Stringers:	82 dB	
3.	Reinforced Concrete Viaduct:	74 dB	
4.	Concrete-Encased Steel:	70 dB	

The actual L_{dn} at a given location is calculated by logarithmically summing the near and far track L_{dn} components at the appropriate distances, assuming a 10 log distance dependence. An average structure column-to-near track distance of 1.5 m (5 ft) and an average track separation of 7.5 m (25 ft) are chosen, based on BBN field observations. The distance correction utilized for calculation of L_{dn} for the NYCTA elevated structures is illustrated in Fig. G-13.

G.3 Fractional Impact Analysis

The fractional impact analysis for the NYCTA elevated structures is accomplished by the method outlined by Schultz [*G.3*]. The steps in this procedure are described below.

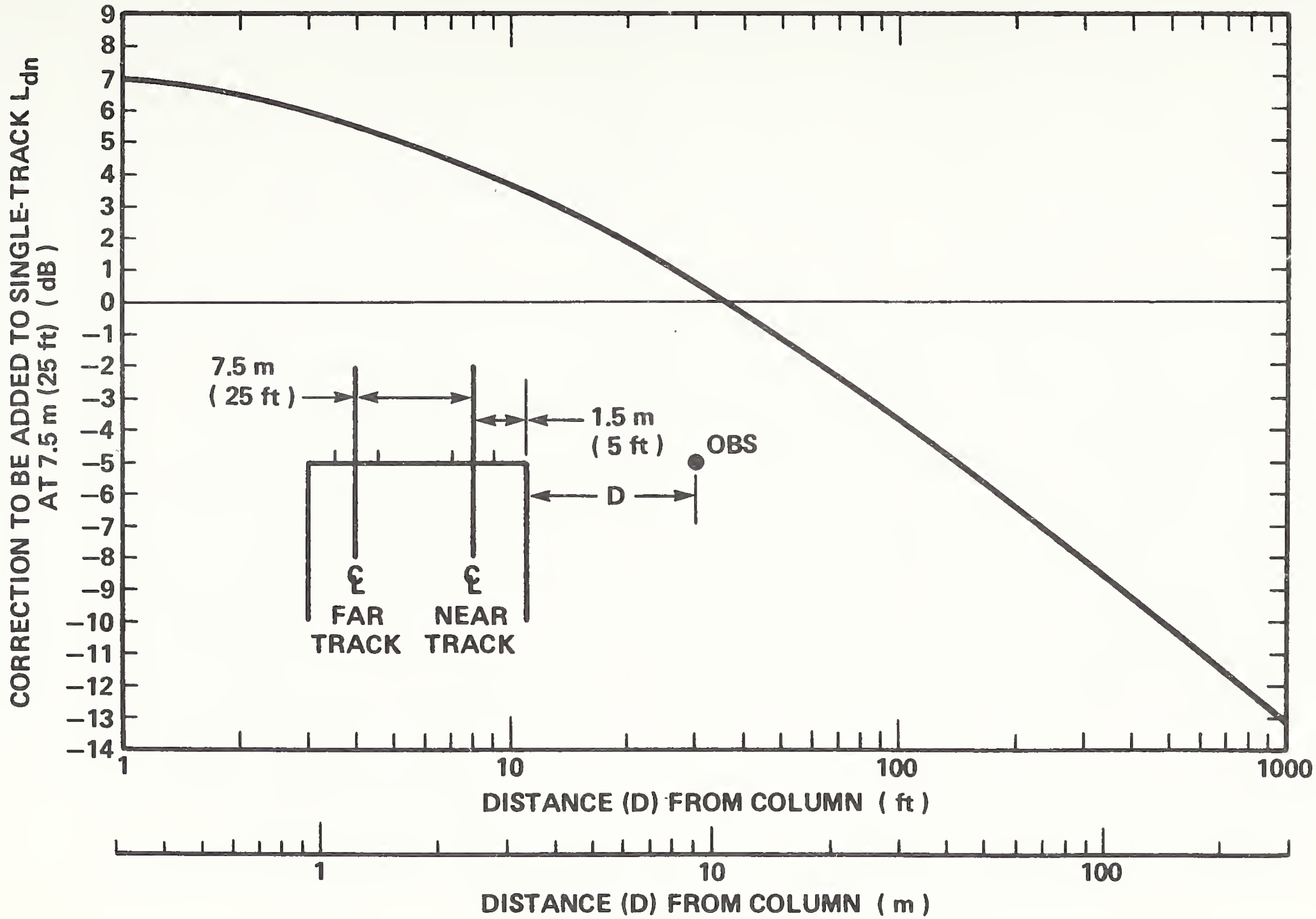


FIGURE G-13. DISTANCE CORRECTION FOR CALCULATION OF L_{dn} FOR NYC TRANSIT SYSTEM ELEVATED STRUCTURES

1. The transit L_{dn} component is estimated, by the method outlined in Sec. G.2, at distances corresponding to the first row of residential and commercial buildings. These distances are obtained from a physical inventory [*G.4*].

2. The population for each block along the elevated lines is obtained from the physical inventory [*G.4*], which determined an average of 0.2 people per ft of block per story.

3. The Sound Level Weighted Population (LWP) for each segment between elevated line stations is calculated by multiplying the population bordering the segment by the noise weighting function (W) corresponding to the transit L_{dn} for the appropriate structure type at each residential/commercial location.

4. The total LWP is calculated for each elevated line, for each structural type and for the entire system by summing the LWPs for the appropriate station-to-station segments. Results are obtained for the following two cases: (a) residential and commercial land uses impacted and (b) only residential land uses impacted.

The above procedure assumes that train noise is never more than 5 dB below the ambient L_{dn} (without trains) at the first row of buildings. The lowest train L_{dn} component encountered in the calculations is 67.5 dB, with most levels in the 80 to 90 dB range. Population data indicate that population densities in 1975 ranged between 18,182 people per square mile for Queens County and 62,132 people per square mile in New York County (Manhattan) [*G.5*]. Ambient noise levels can be estimated based on population density using the following relation [*G.6*]:

$$L_{dn} = 10 \log (\rho) + 22 \text{ dB},$$

where ρ is the population density (people per square mile). This suggests that ambient noise levels (L_{dn}) in New York City range between 65 dB and 70 dB. Therefore, the fractional impact analysis should include all areas exposed to a transit L_{dn} component of 65 dB or greater. Since the lowest train noise encountered was 67.5 dB, the assumption of train noise dominance is considered justifiable.

The results of the fractional impact analysis for the New York City transit system are summarized in Tables G.2, G.3, and G.4. Table G.5 provides noise impact calculation details, listing impact data for station-to-station segments along each elevated line.

The analysis results presented here indicate an estimated total impacted residential population of about 253,000. This is roughly half the number cited in a report prepared by the New York City Bureau of Noise Abatement [*G.7*]. The difference is due to the fact that the present study considers only those residential buildings nearest to the elevated structures (within 65 m or 200 ft) to be impacted, whereas the New York report considers as impacted all people living within 137 m (450 ft) of the elevated lines. It is coincidental that the total LWP of about 476,000 determined in the present study is of the same order as the number of impacted people cited in the New York report.

REFERENCES — APPENDIX G

G.1 Podolsky, H., New York City Transit Authority, letter to Eric Ungar, Bolt Beranek and Newman Inc. (February 1979).

G.2 New York City Transit Authority, Daily Timetable-IRT #2 — 241st Street/White Plains Road Line, Division "A" File No. 2-1012 (15 January 1979).

G.3 Schultz, T.J., "Noise Rating Criteria for Elevated Rapid Transit Structures," BBN Rept. No. 3905 (April 1979).

G.4 Amman & Whitney Consulting Engineers, "Noise Control Design of Elevated Structures — Preliminary Inventory Report — NYCTA System" (8 June 1979).

G.5 U.S. Department of Commerce, Bureau of the Census, "County and City Data Book 1977 — A Statistical Abstract Supplement" (1977).

G.6 U.S. Environmental Protection Agency, "Population Distribution of the United States as a Function of Outdoor Noise Level," Rept. No. EPA-550/9-74-009A (June 1974).

G.7 New York City Environmental Protection Administration, Bureau of Noise Abatement, "Subway Noise in New York City — Rapid Transit Railroad Noise," A Report to the City Council (October 1973).

TABLE G-2. NEW YORK CITY TRANSIT SYSTEM ELEVATED STRUCTURE FRACTIONAL IMPACT ANALYSIS SUMMARY

Elevated Line	Structure Type	Impacted Population		Sound Level Weighted Population	
		Residential and Commercial	Residential Only	Residential and Commercial	Residential Only
Astoria Line	Steel with solid web girders	11,085	8,661	23,672	18,308
Brighton Beach Line	Steel with solid web girders	17,519	15,722	33,213	28,932
Broadway-Jamaica Line	Steel with solid web girders	43,811	28,308	104,416	63,925
Broadway-7th Ave. Line	Steel with solid web girders	24,849	22,821	46,429	42,183
Canarsie Line	Steel with solid web girders	0	0	0	0
Coney Island-Culver Line	Steel with solid web girders	6,966	5,027	14,530	10,276
	Steel with lattice web girders	711	711	943	943
	Concrete-encased steel	3,381	3,114	2,561	2,349
	Total Line	11,058	8,852	18,034	13,568
Flushing Line	Steel with solid web girders	17,066	11,916	40,128	27.143
	Reinforced concrete viaduct	3,956	1,900	3,128	1,482
	Total Line	21,022	13,816	43,256	28,625
Jerome Ave. Line	Steel with solid web girders	17,865	11,439	35,292	21,657
Lefferts Blvd. Line	Steel with solid web girders	7,617	4,926	19,159	12,271
Myrtle Ave. Line	Steel with solid web girders	9,084	5,249	21,693	12,376
New Lots Ave. Line	Steel with solid web girders	15,493	14,464	35,018	32,427
Pelham Line	Steel with solid web girders	30,867	28,944	60,667	57,039
Rockaway Line	Reinforced concrete viaduct	21,329	21,329	17,215	17,215
West End Line	Steel with solid web girders	21,816	8,958	46,100	20,176
White Plains & West Farms Lines	Steel with solid web girders	62,321	59,133	114,159	107,532
Miscellaneous	Steel with solid web girders, open deck (wood tie)	286,359	225,568	594,476	454,245
Coney Island-Culver Line	Steel with lattice web girders, open deck (wood tie)	711	711	943	943
Rockaway/Flushing Lines	Reinforced concrete viaduct, wood tie and ballast	25,285	23,229	20,343	18,697
Coney Island-Culver Line	Concrete-encased steel, wood tie and ballast	3,381	3,114	2,561	2,349
ALL LINES	ALL TYPES	315,736	252,622	618,323	476,234

TABLE G-3. COMMERCIAL AND RESIDENTIAL POPULATION VS NOISE EXPOSURE FOR NEW YORK CITY TRANSIT SYSTEM ELEVATED STRUCTURES

Elevated Line	Structure Type	No. of People Exposed to Elevated Transit Structure Noise Within Various Ranges of L_{dn}, in dB						
		65-70	70-75	75-80	80-85	85-90	90-95	Total
Astoria	Steel with solid web girders				1,250	9,835		11,085
Brighton Beach	Steel with solid web girders			5,100	4,444	7,975		17,519
Broadway-Jamaica	Steel with solid web girders			840	5,009	37,722	240	43,811
Broadway-7th Ave.	Steel with solid web girders				20,081	4,768		24,849
Canarsie	Steel with solid web girders							0
Coney Island-Culver	Steel with solid web girders Steel with lattice web girders Concrete-encased steel Total Line	 1,035 1,035	 1,911 1,911	 620 435 1,055	1,520 91 1,611	5,446 5,446		6,966 711 3,381 11,058
Flushing	Steel with solid web girders Reinforced concrete Total Line		 3,956 3,956		3,076 3,076	13,642 13,642	348 348	17,066 3,956 21,022
Jerome Ave.	Steel with solid web girders				7,631	10,234		17,865
Lefferts Blvd.	Steel with solid web girders					7,617		7,617
Myrtle Ave.	Steel with solid web girders					9,084		9,084
New Lots Ave.	Steel with solid web girders				2,300	13,007	186	15,493
Pelham	Steel with solid web girders				20,954	9,913		30,867
Rockaway	Reinforced concrete	5,560	13,457	2,028	284			21,329
West End	Steel with solid web girders				7,234	14,582		21,816
White Plains & West Farms	Steel with solid web girders				40,276	22,045		62,321
Misc.	Steel with solid web girders, open deck (wood tie)			5,940	113,775	165,870	744	286,359
Coney Island-Culver	Steel with lattice web girders, open deck (wood tie)			620	91			711
Rockaway/Flushing	Reinforced concrete, wood tie and ballast, bolted rail	5,560	17,413	2,028	284			25,285
Coney Island-Culver	Concrete-encased steel, wood tie and ballast, barrier wall	1,035	1,911	435				3,381
All Lines	All Types	6,595	19,324	9,023	114,150	165,870	744	315,736

TABLE G-4. RESIDENTIAL POPULATION VS NOISE EXPOSURE FOR NEW YORK CITY TRANSIT SYSTEM ELEVATED STRUCTURES

Elevated Line	Structure Type	No. of People Exposed to Elevated Transit Structure Noise Within Various Ranges of L_{dn}, in dB						
		65-70	70-75	75-80	80-85	85-90	90-95	Total
Astoria	Steel with solid web girders				1,250	7,411		8,661
Brighton Beach	Steel with solid web girders			5,100	4,444	6,178		15,722
Broadway-Jamaica	Steel with solid web girders			840	4,977	22,491		28,308
Broadway-7th Ave.	Steel with solid web girders				19,151	5,670		22,821
Canarsie	Steel with solid web girders							0
Coney Island-Culver	Steel with solid web girders				1,440	3,587		5,027
	Steel with lattice web girders			620	91			711
	Concrete-encased steel	1,035	1,644	435				3,114
	Total Line	1,035	1,644	1,055	1,531	3,587		8,852
Flushing	Steel with solid web girders				3,076	8,608	232	11,916
	Reinforced concrete		1,900					1,900
	Total Line		1,900		3,076	8,608	232	13,816
Jerome Ave.	Steel with solid web girders				6,415	5,024		11,439
Lefferts Blvd.	Steel with solid web girders					4,926		4,926
Myrtle Ave.	Steel with solid web girders					5,249		5,249
New Lots Ave.	Steel with solid web girders				2,300	12,014	150	14,464
Pelham	Steel with solid web girders				20,454	8,490		28,944
Rockaway	Reinforced concrete	5,560	13,457	2,028	284			21,329
West End	Steel with solid web girders				1,149	7,809		8,958
White Plains & West Farms	Steel with solid web girders				40,276	18,857		59,133
Misc.	Steel with solid web girders, open deck (wood tie)			5,940	104,932	114,314	382	225,568
Coney Island-Culver	Steel with lattice web girders, open deck (wood tie)			620	91			711
Rockaway/Flushing	Reinforced concrete, wood tie and ballast, bolted rail	5,560	15,357	2,028	284			23,229
Coney Island-Culver	Concrete-encased steel, wood tie and ballast, barrier wall	1,035	1,644	435				3,114
All Lines	All types	6,595	17,001	9,023	105,307	114,314	382	252,622

TABLE G-5. NYCTA NOISE IMPACT CALCULATIONS

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit Ldn (dB)	W (Ldn)	Impacted Population (P)		Sound Level Weighted Population (LWP)	
					Residential & Commercial	Residential Only	Residential & Commercial	Residential Only
Astoria Line Open Deck, Solid Web Girders								
Ditmars - Astoria	2,800	20	88.0	2.355	116	--	273	--
		25	87.0	2.219	1,044	828	2,317	1,837
		30	86.5	2.154	812	812	1,749	1,749
Subtotal					1,972	1,640	4,339	3,586
Astoria - 30th Ave.	1,000	30	86.5	2.154	1,393	1,393	3,001	3,001
30th Ave. - Broadway	2,000	25	87.0	2.219	801	801	1,777	1,777
		30	86.5	2.154	834	834	1,796	1,796
Subtotal					1,635	1,635	3,573	3,573
Broadway - 36th Ave.	2,500	30	86.5	2.154	1,475	1,350	3,177	2,908
		70	83.5	1.791	1,250	1,250	2,239	2,239
Subtotal					2,725	2,600	5,416	5,147
36th Ave. - 39th Ave.	1,000	30	86.5	2.154	1,520	1,393	3,254	3,001
39th Ave. - Queens Plaza	1,750	20	88.0	2.355	526	--	1,239	--
		30	86.5	2.154	1,314	--	2,830	--
Subtotal					1,840	--	4,069	--
TOTAL LINE	10,150				11,085	8,661	23,672	18,308
Brighton Beach Line Open Deck, Solid Web Girders								
Coney Island - W. 8th St.	1,300	50	85.0	1.966	2,340	2,340	4,600	4,600
		200	79.5	1.380	2,340	2,340	3,229	3,229
Subtotal					4,680	4,680	7,830	7,830
W. 8th St. - Ocean Pkwy.	2,300	15	88.5	2.425	153	77	371	187
		20	88.0	2.355	843	535	1,985	1,260
		50	85.0	1.966	3,297	3,297	6,482	6,482
		80	83.0	1.736	245	245	425	425
		100	82.5	1.682	1,380	1,380	2,321	2,321
		200	79.5	1.380	2,760	2,760	3,809	3,809
Subtotal					8,678	8,294	15,393	14,484
Ocean Pkwy. - Brighton Bch	1,700	20	88.0	2.355	1,360	680	3,203	1,601
Brighton Bch - Sheepshead Bay	4,000	10	89.5	2.571	400	400	1,028	1,028
		15	88.5	2.425	1,600	867	3,880	2,015
		20	88.0	2.355	800	800	1,884	1,884
Subtotal					2,800	2,067	6,792	5,017
TOTAL LINE	9,300				17,518	15,721	33,213	28,932
Broadway-Jamaica Line Open Deck, Solid Web Girders								
Marcy Ave. - Hewes St.	1,500	15	88.5	2.425	1,800	800	4,365	1,940
Hewes St. - Lorimer St.	1,400	15	88.5	2.425	1,120	630	2,716	1,528
		200	79.5	1.380	840	840	1,159	1,159
Subtotal					1,960	1,470	3,875	2,687

TABLE G-5. NYCTA NOISE IMPACT CALCULATIONS (CONT.)

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit Ldn (dB)	W (L_{dn})	Impacted Population (P)		Sound Level Weighted Population (LWP)	
					Residential & Commercial	Residential Only	Residential & Commercial	Residential Only
Broadway-Jamaica Line (Cont.)								
Lorimer St. - Flushing Ave	2,000	15	88.5	2.425	1,440	720	3,492	1,746
		30	86.5	2.154	70	--	151	--
		40	85.5	2.027	320	240	649	486
		100	82.5	1.682	2,560	2,566	4,306	4,306
Subtotal					4,390	3,520	8,598	6,538
Flushing Ave. - Kosciusko St.	2,100	3	92.0	2.968	240	--	712	--
		15	88.5	2.425	2,240	--	5,432	--
		50	85.0	1.966	490	490	978	978
Subtotal					2,970	490	7,122	978
Kosciusko St. - Gates Ave	2,100	15	88.5	2.425	1,932	1,092	4,685	2,648
Gates Ave. - Hasley St.	2,300	15	88.5	2.425	2,185	1,265	5,299	3,068
		100	82.5	1.682	1,500	1,500	2,523	2,523
Subtotal					3,685	2,765	7,822	5,591
Hasley St. - Chauncey St.	1,700	15	88.5	2.425	1,504	646	3,647	1,567
Chauncey St. - Eastern Pkwy	1,400	15	88.5	2.425	504	280	1,222	679
		30	86.3	2.154	1,120	1,120	2,412	2,412
		40	85.5	2.027	336	280	681	568
		100	82.5	1.682	672	672	1,130	1,130
Subtotal					2,632	2,352	5,446	4,789
Eastern Pkwy - Alabama Ave.	2,000	--	--	--	--	--	--	--
Alabama Ave. - Van Siclen Ave.	2,200	15	88.5	2.425	1,764	1,260	4,278	3,056
		50	85.0	1.966	63	--	124	--
Subtotal					1,827	1,260	4,402	3,056
Van Siclen Ave. - Cleveland St.	1,700	12	89.0	2.497	1,849	1,022	4,617	2,552
Cleveland St. - Norwood Ave	1,900	12	89.0	2.497	1,584	1,141	3,955	2,849
Norwood Ave. - Crescent St.	2,100	15	88.5	2.425	1,960	1,160	4,753	2,813
Crescent St. - Cypress Hills	2,800	15	88.5	2.425	1,989	1,989	4,823	4,823
Cypress Hills - Elderts Lane	1,700	12	89.0	2.497	192	79	479	197
		15	85.5	2,425	146	49	354	119
Subtotal					338	128	833	316
Elderts Lane - Forest Pkwy.	1,800	12	89.0	2.497	1,728	1,152	4,315	2,877
		40	85.5	2.027	144	144	292	292
Subtotal					1,872	1,296	4,607	3,169
Forest Pkwy. - Woodhaven Blvd.	2,400	12	89.0	2.497	2,188	1,227	5,463	3,064
Woodhaven Blvd. - 102nd St.	2,000	12	89.0	2.497	700	450	1,748	1,124
		15	88.5	2.425	950	350	2,304	849
Subtotal					1,650	800	4,052	1,472
102nd St. - 111st St.	2,000	12	89.0	2.497	1,800	1,000	4,495	2,497
111st St. - 120th St.	2,800	12	89.0	2.497	1,433	620	3,578	1,548
		15	88.5	2.425	1,243	930	3,014	2,255
Subtotal					1,676	1,550	6,592	3,803

TABLE G-5. NYCTA NOISE IMPACT CALCULATIONS (CONT.)

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit Ldn (dB)	W (Ldn)	Impacted Population (P)		Sound Level Weighted Population (LWP)	
					Residential & Commercial	Residential Only	Residential & Commercial	Residential Only
Broadway-Jamaica Line (Cont.)								
120th St. - Metropolitan Ave.	1,600	12	89.0	2.497	1,786	1,112	4,460	2,777
Metropolitan Ave. - Queens Blvd.	1,700	12 40	89.0 85.5	2.497 2.027	685 91	320 91	1,710 184	799 184
Subtotal					776	411	1,895	983
Queens Blvd. - Sutphin Blvd.	1,700	12 15 40	89.0 88.5 85.5	2.497 2.425 2.027	849 453 340	510 227 340	2,120 1,099 689	1,273 550 689
Subtotal					1,642	1,077	3,908	2,513
TOTAL LINE	45,200				43,810	28,308	104,416	63,925
Broadway-7th Ave. Line Open Deck, Solid Web Girder								
Portal - 125th St.	1,200	50 60 100	84.8 84.1 82.2	2.027 1.848 1.682	640 960 3,520	560 960 3,520	1,297 1,774 5,921	1,135 1,774 5,921
Subtotal					5,120	5,040	8,992	8,830
125th St. - 133rd St. Portal	1,400	50 60 80	84.8 84.1 83.2	2.027 1.848 1.736	896 336 2,240	504 336 2,240	1,816 621 3,889	1,022 621 3,889
Subtotal					3,472	3,080	6,326	5,532
Abutment @ Dykeman - 207th St.	2,000	20 30 100	87.8 86.5 82.2	2.355 2.154 1.682	660 2,000 3,000	600 1,800 3,000	1,554 4,308 5,046	1,413 3,877 5,046
Subtotal					5,660	5,400	10,908	10,336
207th St. - 215th St.	1,750	30 80 100	86.5 83.2 82.2	2.154 1.736 1.682	700 420 --	630 420 --	1,508 729 --	1,357 729 --
Subtotal					1,120	1,050	2,237	2,086
215th St. - 225th St.	2,200	50 80	84.8 83.2	2.027 1.736	110 660	-- 660	223 1,146	-- 1,146
Subtotal					770	660	1,369	1,146
225th St. - 231st St.	2,000	20 30 60 70 80	87.8 86.5 84.1 83.8 83.2	2.355 2.154 1.848 1.848 1.736	100 200 1,000 3,000 600	-- -- 1,000 3,000 600	236 431 1,848 5,544 1,042	-- -- 1,848 5,544 1,042
Subtotal					4,900	4,600	9,101	8,434
231st St. - 238th St.	2,250	30 50 70 100	86.5 84.8 83.8 82.2	2.154 2.027 1.848 1.682	625 125 750 750	250 -- 750 625	1,346 253 1,386 1,262	539 -- 1,386 1,051
Subtotal					2,250	1,625	4,247	2,976
238th St. - Van Cortland	1,950	25 50	87.2 84.8	2.219 2.027	483 1,074	390 976	1,072 2,177	865 1,978
Subtotal					1,557	1,366	3,249	2,843
TOTAL LINE	14,750				24,849	22,821	46,429	42,183

TABLE G-5. NYCTA NOISE IMPACT CALCULATIONS (CONT.)

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit Ldn (dB)	W (Ldn)	Impacted Population (P) Residential & Commercial	Impacted Population (P) Residential Only	Sound Level Weighted Population (LWP) Residential & Commercial	Sound Level Weighted Population (LWP) Residential Only
Canarsie Line Open Deck, Solid Web Girders	9,500	--	--	--	0	0	0	0
Coney Island Culver Line Open Deck, Solid Web Girders								
Abutment - Ditmas Ave.	1,000	--	--	--	--	--	--	--
Ditmas Ave. - 18th Ave.	1,600	30 100	86.5 82.5	2.154 1.682	1,120 160	720 80	2,412 269	1,551 135
Subtotal					1,280	800	2,682	1,685
18th Ave. - Ave I	1,600	20 30	88.0 86.5	2.355 2.154	481 160	267 107	1,133 345	629 230
Subtotal					641	374	1,478	858
Ave. I - 22nd Ave.	1,800	20	88.0	2.355	720	420	1,696	989
22nd Ave. - Ave. N	2,200	--	--	--	--	--	--	--
Ave. N - Ave. P	1,800	30	86.5	2.154	585	315	1,260	679
Ave. P - Kings Hwy.	1,500	30	86.5	2.154	600	450	1,292	969
Kings Hwy. - Ave. U	2,500	30	86.5	2.154	928	785	1,999	1,681
Ave. U - Ave. X	2,300	30	86.5	2.154	852	523	1,835	1,127
Van Siclen - W. 8th	1,700	100	82.5	1.682	1,360	1,360	2,288	2,288
Total Structure	18,000				6,966	5,027	14,530	10,276
Coney Island Line Open Deck, Lattice Web Girders								
Ave. X - Van Siclen	3,100	40 100	81.5 78.5	1.577 1.289	91 620	91 620	144 799	144 799
Subtotal					711	711	943	943
Total Structure	3,100				711	711	943	943
Tie and Ballast Track Concrete Encased Steel Structure								
Abutment - Smith - 9th	1,000	20 50	72.0 69.0	0.822 0.636	400 600	400 600	329 382	329 382
Subtotal					1,000	1,000	710	710
Smith-9th - 4th Ave.	2,900	0 30 60	77.0 70.5 68.0	1.159 0.694 0.554	435 870 435	435 870 435	504 604 237	504 604 237
Subtotal					1,740	1,740	1,345	1,345
4th Ave. - Abutment	1,600	20 30	72.0 70.5	0.822 0.694	481 160	267 107	395 111	219 74
Subtotal					641	374	506	294
Total Structure	5,500				3,381	3,114	2,561	2,349
TOTAL LINE	26,600				11,058	8,852	18,034	13,568

TABLE G-5. NYCTA NOISE IMPACT CALCULATIONS (CONT.)

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit Ldn (dB)	W (Ldn)	Impacted Population (P) Residential & Commercial	Impacted Population (P) Residential Only	Sound Level Weighted Population (LWP) Residential & Commercial	Sound Level Weighted Population (LWP) Residential Only
Flushing Line Open Deck, Solid Web Girder								
Queens Plaza - 33rd St.	2,400	10	89.5	2.571	240	--	617	--
51st St. - 61st St.	2,400	8	90.0	2.647	696	464	1,842	1,228
		10	89.5	2.571	338	116	869	298
		12	89.0	2.497	348	232	869	579
		15	88.5	2.425	1,276	928	3,088	2,250
		20	88.0	2.355	232	232	546	546
Subtotal					2,890	1,972	7,214	4,901
61st St. - 69th St.	1,750	10	89.5	2.571	117	--	301	--
		15	88.5	2.425	933	466	2,263	1,130
Subtotal					1,050	466	2,564	1,130
69th St. - 74th St.	1,300	10	89.5	2.571	346	192	890	494
		15	88.5	5.425	87	--	211	--
		20	88.0	2.355	87	--	205	--
		60	84.0	1.848	520	520	961	961
Subtotal					1,040	712	2,260	1,455
74th St. - 82nd St.	2,400	10	89.5	2.571	1,056	192	2,715	494
82nd St. - 90th St.	2,200	10	89.5	2.571	1,584	528	4,072	1,357
		60	84.0	1.848	1,086	1,056	1,951	1,951
Subtotal					2,640	1,584	6,024	3,308
90th St. - Junction Blvd.	2,000	10	89.5	2.571	1,200	650	3,085	1,671
		40	85.5	2.027	300	300	608	608
		60	84.0	1.848	500	500	924	924
Subtotal					2,000	1,450	4,617	3,203
Junction Blvd. - 103rd St.	2,200	10	89.5	2.571	660	550	1,697	1,414
		20	88.0	2.355	330	330	777	777
		30	86.5	2.154	660	660	1,422	1,422
Subtotal					1,650	1,540	3,896	3,813
103rd St. - 111th St.	2,000	10	89.5	2.571	1,600	1,500	4,114	3,857
		15	88.5	2.425	300	300	676	676
Subtotal					1,900	1,800	4,790	4,533
111th St. - Willets Ave.	2,500	10	89.5	2.571	300	200	771	514
		15	88.5	2.425	300	--	728	--
Subtotal					600	200	1,499	514
Willets Ave. - Abutment	4,000	50	85.0	1.960	2,000	2,000	3,932	3,932
Total Structure	25,150				17,066	11,916	49,125	27,143
Tie and Ballast Track, Concrete Viaduct								
33rd St. - 40th St.	2,000	50	73.0	0.855	1,400	500	1,197	257
		80	71.0	0.725	600	500	435	435
Subtotal					2,000	1,000	1,632	692
40th St.	1,750	50	73.0	0.855	1,160	300	992	257
		80	71.0	0.725	696	600	505	435
Subtotal					1,956	900	1,497	692
Total Structure	3,750				3,956	1,900	3,128	1,482
TOTAL LINE	28,900				21,022	13,816	47,411	30,625

TABLE G-5. NYCTA NOISE IMPACT CALCULATIONS (CONT.)

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit Ldn (dB)	W (Ldn)	Impacted Population (P) Residential & Commercial	Impacted Population (P) Residential Only	Sound Level Weighted Population (LWP) Residential & Commercial	Sound Level Weighted Population (LWP) Residential Only
Jerome Avenue Line Open Deck, Solid Web Girders								
156th St. - 161st St.	1,500	15	88.5	2.425	1,000	600	2,425	1,455
161st St. - 167th St.	3,000	15	88.5	2.425	120	--	291	--
		100	82.5	1.682	1,680	1,680	2,826	2,826
Subtotal					1,800	1,680	3,117	2,826
167th St. - 170th St.	1,900	15	88.5	2.425	229	--	555	--
		50	85.0	1.966	304	--	598	--
		100	82.5	1.682	532	--	895	--
		150	81.0	1.526	532	--	812	--
Subtotal					1,597		2,860	
170th St. - Mt. Eden Ave.	1,500	15	88.5	2.425	150	--	364	--
		100	82.5	1.682	1,575	1,575	2,649	2,649
Subtotal					1,725	1,575	3,013	2,649
Mt. Eden Ave. - 176th St.	1,600	15	88.5	2.425	512	448	1,242	1,086
		100	82.5	1.682	1,344	1,344	2,261	2,244
Subtotal					1,856	1,792	3,502	3,330
176th St. - Burnside Ave.	2,200	15	88.5	2.425	792	--	1,921	--
		150	81.0	1.526	616	616	940	940
Subtotal					1,408	616	2,861	940
Burnside Ave. - 183rd St.	1,700	30	86.5	2.154	1,020	476	2,197	1,025
183rd St. - Fordham Rd.	1,600	30	86.5	2.154	800	580	1,723	1,249
Fordham Rd. - Kingsbridge Rd.	1,900	30	86.5	2.154	1,140	760	2,456	1,637
		40	85.5	2.027	456	--	924	--
Subtotal					1,596	760	3,380	1,637
Kingsbridge Rd. - Bedford Pkwy.	3,000	30	86.5	2.154	443	--	954	--
		40	85.5	2.027	1,200	1,200	2,432	2,432
		80	83.0	1.736	1,200	1,200	2,083	2,083
Subtotal					2,843	2,400	5,470	4,516
Bedford Pkwy. - Mosholu Pkwy.	3,000	30	86.5	2.154	600	300	1,292	646
		40	85.5	2.027	300	300	608	608
Subtotal					900	600	1,901	1,254
Mosholu Pkwy. - Woodlawn	3,000	30	86.5	2.154	1,320	360	2,843	775
TOTAL LINE	25,900				17,865	11,439	35,292	21,657
Lefferts Blvd. Line Open Deck, Solid Web Girders								
Lefferts Blvd. - 111th St.	2,000	10	89.5	2.571	1,920	1,147	4,936	2,949
111th St. - 104th St.	1,700	10	89.5	2.571	1,446	766	3,718	1,969
104th St. - Rockaway Blvd.	1,900	10	89.5	2.571	761	380	1,957	977
		20	88.0	2.355	380	253	895	596
Subtotal					1,141	633	2,851	1,573

TABLE G-5. NYCTA NOISE IMPACT CALCULATIONS (CONT.)

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit Ldn (dB)	W (Ldn)	Impacted Population (P)		Sound Level Weighted Population (LWP)	
					Residential & Commercial	Residential Only	Residential & Commercial	Residential Only
Lefferts Blvd. Line (Cont.)								
Rockaway Blvd. - 88th St.	2,000	10	89.5	2.571	900	400	2,314	1,028
88th St. - 80th St.	2,000	10	89.5	2.571	1,100	1,000	2,828	2,571
		50	85.0	1.966	200	200	393	393
Subtotal					1,300	1,200	3,221	2,964
80th St. - Abutment	1,300	10	89.5	2.571	130	--	334	--
		15	88.5	2.425	520	520	1,261	1,261
		40	88.5	2.027	260	260	527	527
Subtotal					910	780	2,122	1,788
TOTAL LINE	10,900				7,617	4,926	19,159	12,271
Myrtle Avenue Line Open Deck, Solid Web Girders								
Fresh Pond - Forest Ave.	1,500	--	--	--	--	--	--	--
Forest Ave. - Seneca Ave.	2,500	--	--	--	--	--	--	--
Seneca Ave. - Wycoff Ave.	2,000	10	89.5	2.571	400	--	1,028	--
		20	88.0	2.355	100	--	236	--
		30	86.5	2.154	900	900	1,939	1,939
Subtotal					1,400	900	3,203	1,939
Wycoff Ave. - Knickerbocker	1,800	13	89.0	2.497	72	--	180	--
		15	88.5	2.425	1,080	648	2,619	1,571
		30	86.5	2.154	144	--	310	--
Subtotal					1,296	648	3,109	1,571
Knickerbocker - Central Ave.	2,000	15	88.5	2.425	4,080	2,320	9,894	5,626
		50	85.0	1.966	240	240	472	472
Subtotal					4,320	2,560	10,366	6,099
Central Ave. - Myrtle Ave.	2,500	15	88.5	2.425	2,068	1,141	5,015	2,767
TOTAL LINE	12,300				9,084	5,249	21,693	12,376
New Lots Ave. Line Open Deck, Solid Web Girders								
Abutment - New Lots Ave.	800	10	89.5	2.571	1,120	960	2,880	2,468
New Lots Ave. - Van Siclen Ave.	1,600	10	89.5	2.571	959	959	2,466	2,466
Van Siclen Ave. - Penn. Ave.	1,600	--	--	--	--	--	--	--
Penn. Ave. - Junius St.	2,100	10	89.5	2.571	1,960	1,540	5,039	3,959
Junius St. - Rockaway Ave.	2,000	10	89.5	2.571	160	160	411	411
		25	87.0	2.219	4,480	4,480	9,941	9,941
		30	86.5	2.154	1,200	1,120	2,585	2,412
		120	82.0	1.682	720	720	1,211	1,211
Subtotal					6,560	6,480	14,148	13,975
Rockaway Ave. - Saratoga Ave.	1,800	10	89.5	2.571	630	630	1,620	1,620
		50	85.0	1.966	540	540	1,062	1,062
		100	82.5	1.682	270	270	454	454
Subtotal					1,440	1,440	3,136	3,136

TABLE G-5. NYCTA NOISE IMPACT CALCULATIONS (CONT.)

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit Ldn (dB)	W (L_{dn})	Impacted Population (P) Residential & Commercial	Impacted Population (P) Residential Only	Sound Level Weighted Population (LWP) Residential & Commercial	Sound Level Weighted Population (LWP) Residential Only
New Lots Ave. Line (Cont.)								
Saratoga Ave. - Sutter Ave.	2,600	8	90.0	2.647	372	299	985	791
		10	89.5	2.571	372	149	956	383
		30	87.0	2.154	744	670	1,603	1,443
		40	85.5	2.027	596	596	1,208	1,208
		100	82.5	1.682	1,040	1,040	1,749	1,749
Subtotal					3,124	2,754	6,501	5,575
Sutter Ave. - Abutment	1,100	10	89.5	2.571	330	330	848	848
TOTAL LINE	13,600				15,493	14,463	35,018	32,427
Pelham Line Open Deck, Solid Web Girders								
Abutment - Whitlock	1,000	--	--	--	--	--	--	--
Whitlock - Elder	2,400	40	85.5	2.027	800	800	1,622	1,622
		100	82.5	1.682	2,880	2,880	4,844	4,844
Subtotal					3,680	3,680	6,466	6,466
Elder - Morrison	1,400	40	85.5	2.027	467	467	947	947
		100	82.5	1.682	2,880	2,880	4,844	4,844
Subtotal					3,347	3,347	5,791	5,791
Morrison - St. Lawrence	2,100	30	86.5	2.154	315	315	679	679
		40	85.5	2.027	1,260	1,260	2,554	2,554
		100	82.5	1.682	2,100	2,100	3,532	3,532
Subtotal					3,675	3,675	6,765	6,765
St. Lawrence - 177th St.	1,900	40	85.5	2.027	950	380	1,926	770
		60	84.0	1.848	285	285	527	527
		100	82.5	1.682	1,520	1,520	2,557	2,557
		150	81.0	1.526	570	570	870	870
Subtotal					3,325	2,755	5,879	4,723
177th St. - Castle Hill	2,700	40	85.5	2.027	756	459	1,532	930
		80	83.0	1.736	810	810	1,406	1,406
		100	82.5	1.682	3,105	3,105	5,223	5,223
Subtotal					4,671	4,374	8,161	7,559
Castle Hill - Zarega Ave.	1,800	20	88.0	2.355	270	270	636	636
		30	86.5	2.154	540	540	1,136	1,136
		40	85.5	2.027	450	360	912	912
		100	82.5	1.682	540	540	908	908
Subtotal					1,800	1,710	3,592	3,592
Zarega Ave. - Westchester Sq.	1,500	40	85.5	2.027	200	--	405	--
		50	85.0	1.966	200	200	393	393
		80	83.0	1.736	500	--	868	--
		100	82.5	1.682	600	600	1,009	1,009
Subtotal					1,500	800	2,676	1,402
Westchester Sq. - Middle-town Rd.	200	10	89.5	2.571	400	267	1,028	686
		40	85.5	2.027	133	--	270	--
Subtotal					533	267	1,298	686

TABLE G-5. NYCTA NOISE IMPACT CALCULATIONS (CONT.)

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit Ldn (dB)	W (L_{dn})	Impacted Population (P) Residential & Commercial	Impacted Population (P) Residential Only	Sound Level Weighted Population (LWP) Residential & Commercial	Sound Level Weighted Population (LWP) Residential Only
Pelham Line (Cont.)								
Middletown Rd. - Buhre Ave.	1,700	40	85.5	2.027	2,040	2,040	4,135	4,135
		100	82.5	1.682	2,040	2,040	3,431	3,431
Subtotal					4,080	4,080	7,566	7,566
Buhre Ave. - Pelham Bay Park Pkwy	2,800	40	85.5	2.027	1,232	1,232	2,497	2,497
		80	83.0	1.736	560	560	972	972
		100	82.5	1.682	2,464	2,464	4,144	4,144
Subtotal					4,256	4,256	7,614	7,614
TOTAL LINE	21,300				30,867	28,944	60,667	57,039
Rockaway Line Tie and Ballast Track, Concrete Viaduct								
Rockaway Pkwy. - Seaside	330	5	79.0	1.384	330	330	457	457
		150	69.0	0.607	3,960	3,960	2,404	2,404
Subtotal					4,290	4,290	2,860	2,860
Seaside - Playland	2,000	20	76.0	1.078	400	400	431	431
		25	75.0	1.0	133	133	133	133
		200	67.5	0.528	1,600	1,600	950	950
Subtotal					2,133	2,133	1,515	1,515
Playland - Holland	2,000	15	76.5	1.110	267	267	299	299
		30	74.5	0.963	267	267	257	257
		40	73.5	0.890	1,067	1,067	950	950
Subtotal					1,601	1,601	1,505	1,505
Holland - Gaston	5,700	2	80.0	1.428	568	568	811	811
		30	74.5	0.963	712	712	682	682
		40	73.5	0.890	712	712	634	634
		50	73.0	0.855	568	568	486	486
		60	72.0	0.788	142	142	112	112
		70	71.5	0.756	1,424	1,424	1,077	1,077
		80	71.0	0.725	854	854	619	619
Subtotal					4,980	4,980	4,424	4,424
Gaston - Straiton	220	40	73.5	0.890	514	514	457	457
		80	71.0	0.725	3,010	3,010	2,182	2,182
Subtotal					3,524	3,524	2,640	2,640
Straiton - Frank	4,500	—	--	—	--	--	--	--
Frank - Edgemere	2,000	40	73.5	0.890	200	200	178	178
				Sub Σ	16,728	16,728	13,120	13,120
Edgemere - Wavecrest	2,000	20	76.0	1.078	400	400	431	431
		40	73.5	0.890	400	400	356	356
		60	72.0	0.788	400	400	315	315
		70	71.5	0.756	600	600	454	454
Subtotal					1,800	1,800	1,556	1,556
Wavecrest - Mott Ave.	2,800	20	76.0	1.078	280	280	302	302
		30	74.5	0.963	840	840	809	809
		40	73.5	0.890	840	840	748	748
		50	73.0	0.855	280	280	239	239
		60	72.0	0.788	560	560	441	441
Subtotal					2,800	2,800	2,539	2,539
TOTAL LINE	26,500				21,328	21,328	17,215	17,215

TABLE G-5. NYCTA NOISE IMPACT CALCULATIONS (CONT.)

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit L_{dn} (dB)	W (L_{dn})	Impacted Population (P) Residential & Commercial	Impacted Population (P) Residential Only	Sound Level Weighted Population (LWP) Residential & Commercial	Sound Level Weighted Population (LWP) Residential Only
West End Line Open Deck, Solid Web Girders								
9th Ave. - Ft. Hamilton	1,800	15	88.5	2.425	840	600	2,037	1,455
Ft. Hamilton - 50th St.	1,700	15	88.5	2.425	1,785	1,063	4,329	2,578
50th St. - 55th St.	1,400	15	88.5	2.425	1,512	952	3,667	2,309
55th St. - 62nd St.	2,000	15	88.5	2.425	1,666	929	4,040	2,293
		70	83.5	1.791	267	267	478	478
Subtotal					1,933	1,196	4,518	2,731
62nd St. - 71st St.	2,400	15	88.5	2.425	1,470	720	3,565	1,746
		50	85.0	1.966	180	180	354	354
Subtotal					1,650	900	3,919	2,100
71st St. - 18th Ave.	2,200	15	88.5	2.425	1,029	637	2,495	1,545
		50	85.0	1.966	98	49	193	96
Subtotal					1,127	686	2,688	1,641
18th Ave. - 20th Ave.	1,500	15	88.5	2.425	150	100	364	243
		25	87.0	2.219	50	--	111	--
		30	86.5	2.154	750	400	1,616	862
Subtotal					950	500	2,091	1,105
20th Ave. - Bay Pkwy.	1,400	30	86.5	2.154	1,040	360	2,240	775
Bay Pkwy. - 25th Ave.	2,300	20	88.0	2.355	255	128	601	301
		30	86.5	2.154	561	--	1,208	--
		40	85.5	1.966	612	102	1,203	201
		100	82.5	1.682	102	102	172	172
Subtotal					1,530	332	3,184	674
25th Ave. - Bay 50th St.	3,100	15	88.5	2.425	138	138	335	335
		40	85.5	2.027	1,103	483	2,236	979
		50	85.0	1.966	964	964	1,895	1,895
		100	82.5	1.682	244	183	410	308
Subtotal					2,449	1,768	4,876	3,517
Bay 50th St. - Abutment	400	30	86.5	2.154	1,000	600	2,154	1,292
		80	83.0	1.736	6,000	--	10,416	--
Subtotal					7,000	600	12,570	1,292
TOTAL LINE	23,800				21,816	8,957	46,100	20,176
White Plains & West Farms Line Open Deck, Solid Web Girders								
Abutment - Jackson Ave.	500	30	86.5	2.154	175	100	377	215
		100	82.5	1.682	1,125	1,125	1,892	1,892
Subtotal					1,300	1,225	2,269	2,107
Jackson Ave. - Prospect Ave.	1,900	30	86.5	2.154	333	--	717	--
		40	85.5	2.027	3,801	3,658	7,705	7,415
		70	83.5	1.791	475	475	851	851
		80	83.0	1.736	1,425	1,425	2,474	2,474
Subtotal					6,034	5,548	11,747	10,740
Prospect Ave. - Intervale Ave.	1,800	30	86.5	2.154	480	480	1,034	1,034
		40	85.5	2.027	480	--	973	--
		100	82.5	1.682	600	600	1,009	1,009
Subtotal					1,560	1,080	3,016	2,043

TABLE G-5. NYCTA NOISE IMPACT CALCULATIONS (CONT.)

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit Ldn (dB)	W (L_{dn})	Impacted Population (P)		Sound Level Weighted Population (LWP)	
					Residential & Commercial	Residential Only	Residential & Commercial	Residential Only
White Plains & West Farms Line (Cont.)								
Intervale Ave. - Simpson	1,400	40	85.5	2.027	1,214	934	2,461	1,893
		70	83.5	1.791	467	467	836	836
Subtotal					1,781	1,401	3,297	2,730
Simpson - Freeman	2,000	20	88.0	2.355	800	700	1,884	1,649
		30	86.5	2.154	300	200	646	431
		40	85.5	2.027	750	550	1,526	1,115
		100	82.5	1.682	500	500	841	841
Subtotal					2,350	1,950	4,891	4,036
Freeman - 174th St.	3,700	40	85.5	2.027	5,624	5,624	11,400	11,400
174th St. - E. Tremont	2,500	40	85.5	2.027	250	--	507	--
		80	83.0	1.736	2,250	2,250	3,906	3,906
Subtotal					2,500	2,250	4,413	3,906
				Sub Σ	21,149	19,078	41,033	36,962
E. Tremont - 180th St.	3,000	100	82.5	1.682	3,600	3,600	6,055	6,055
180th St. - Abutment	500	--	--	--	--	--	--	--
Abutment - Bronx Pkwy E.	500	10	89.5	2.571	600	600	1,543	1,543
Bronx Pkwy E. - Pelham Pkwy.	2,100	10	89.5	2.571	420	420	1,080	1,080
		100	82.5	1.682	3,024	3,024	5,086	5,086
Subtotal					3,444	3,444	6,160	6,160
Pelham Pkwy. - Allerton	3,000	100	82.5	1.682	11,100	11,100	18,670	18,670
		150	81.0	1.526	2,400	2,400	3,662	3,662
Subtotal					13,500	13,500	22,332	22,332
Allerton - Burke	1,900	40	85.5	2.027	254	--	515	--
		70	83.5	1.791	507	507	908	908
		100	82.5	1.682	1,140	1,140	1,917	1,917
Subtotal					1,901	1,647	3,340	2,825
Burke Ave. - Gun Hill Rd.	2,200	40	85.5	2.027	440	--	892	--
		70	83.5	1.791	3,300	3,300	5,910	5,910
		100	82.5	1.682	660	660	1,110	1,110
		150	81.0	1.526	660	660	1,007	1,007
Subtotal					5,060	4,620	8,919	8,027
Gun Hill Rd. - 219th St.	2,600	20	88.0	2.355	312	312	735	735
		30	86.5	2.154	308	308	448	448
		40	85.5	2.027	832	832	1,686	1,686
		70	83.5	1.791	312	312	559	559
		80	83.0	1.736	208	208	361	361
		100	82.5	1.682	416	416	700	700
		150	81.0	1.526	312	312	476	476
Subtotal					2,600	2,600	4,965	4,965

TABLE G-5. NYCTA NOISE IMPACT CALCULATIONS (CONT.)

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit Ldn (dB)	W (Ldn)	Impacted Population (P) Residential & Commercial	Impacted Population (P) Residential Only	Sound Level Weighted Population (LWP) Residential & Commercial	Sound Level Weighted Population (LWP) Residential Only
White Plains & West Farms Line (Cont.)								
219th St. - 225th St.	2,300	40	85.5	2.027	2,145	2,145	4,348	4,348
		100	82.5	1.682	1,815	1,815	3,053	3,053
Subtotal					3,960	3,960	7,401	7,401
225th St. - 233rd St.	1,600	40	85.5	2.027	400	400	811	811
		80	83.0	1.736	640	640	111	111
		100	82.5	1.682	1,360	1,360	2,288	2,288
Subtotal					2,400	2,400	4,210	4,210
233rd St. - Neraid Ave.	1,800	40	85.5	2.027	360	360	730	730
		80	83.0	1.736	720	720	1,250	1,250
		100	82.5	1.682	1,260	1,260	2,119	2,119
Subtotal					2,340	2,340	4,099	4,099
Neraid Ave. - 241st St.	2,000	15	88.5	2.425	400	400	970	970
		30	86.5	2.154	1,200	667	2,585	1,436
		40	85.5	2.027	267	267	541	541
Subtotal					1,867	1,334	4,096	2,947
TOTAL LINE	37,300				62,421	59,133	114,159	107,532

APPENDIX H: PATCO INVENTORY

H.1 Elevated Structure Description

The PATCO transit system includes two segments of elevated structure, comprising a total length of 1.38 km (0.857 miles), located in the vicinity of the Westmont and Collingswood, NJ stations. The structure consists of concrete, with longitudinal concrete beams supporting an 8-in.-thick concrete slab deck (see Fig. H-1). The beams are supported by a single concrete girder at each pier, which in turn is supported by one or two columns, depending on track separation (see Figs. H-2 and H-3). The track consists of continuous welded rail, mounted on the concrete deck with resilient rail fasteners (see Fig. H-4).

Note that bridges (e.g., the Benjamin Franklin Bridge) are not considered elevated transit structures for the present purpose.

H.2 Noise Estimation

Noise measurements conducted by BBN [*H.1*] indicate an average single event noise exposure level (SENEL) of 95 dBA at 15 m (50 ft) for 2-car train passbys at 97 km/h (60 mph). For the purpose of this analysis, train speeds are assumed to average 32 km/h (20 mph) within 300 m (1000 ft) of the stations, 56 km/h (35 mph) between 300 and 460 m (1000 and 1500 ft) from the stations, and 97 km/h (60 mph) between 460 and 610 m (1500 and 2000 ft) from the stations. SENEL is assumed to vary as 20 log (speed) and 10 log (no. of cars). Thus, baseline passby noise levels for single cars on the PATCO elevated structure are estimated to be:

SENEL (15 m) = 92 dBA at 97 km/h (60 mph)
= 87 dBA at 56 km/h (35 mph)
= 82 dBA at 32 km/h (20 mph) .

FIGURE H-1. PATCO ELEVATED TRANSIT STRUCTURE

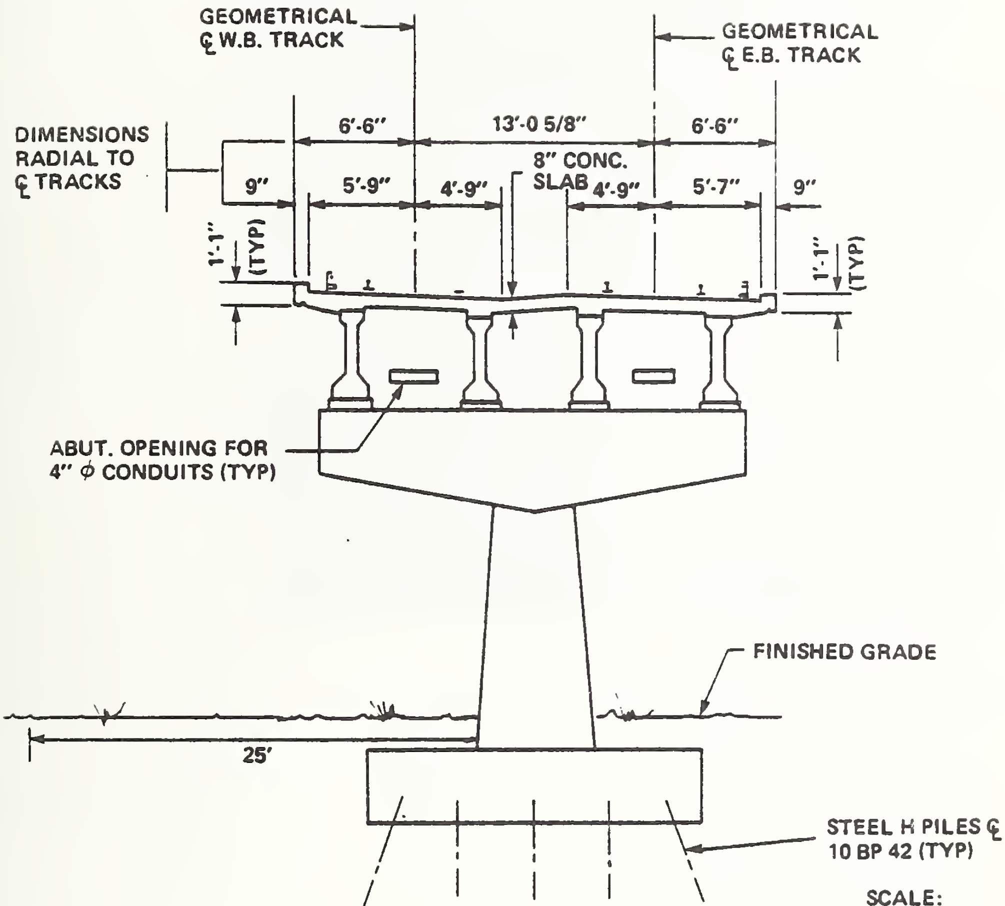


FIGURE H-2. PATCO ELEVATED TRANSIT STRUCTURE CROSS-SECTION AT WESTMONT PIER NO. 5

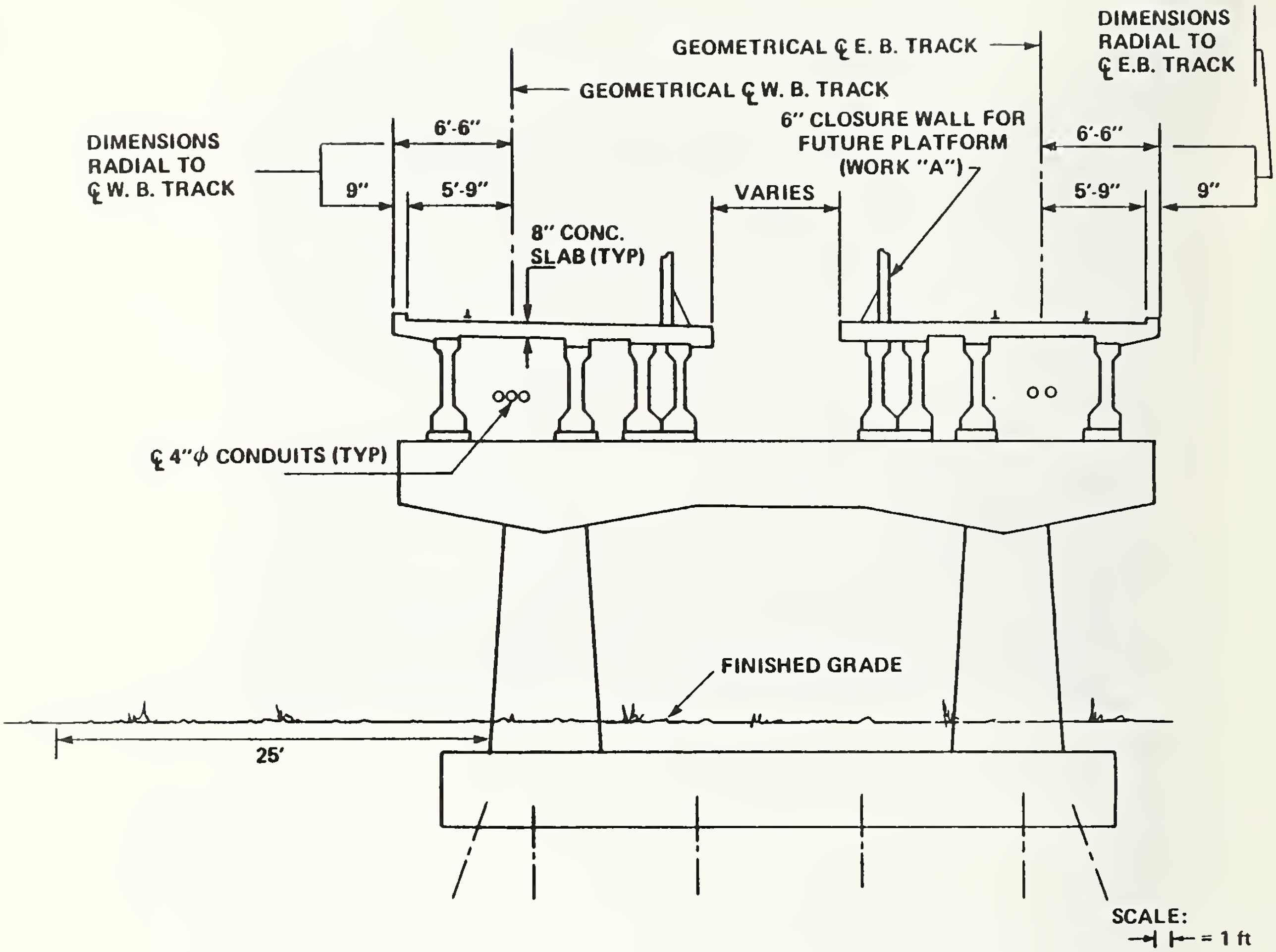


FIGURE H-3. PATCO ELEVATED TRANSIT STRUCTURE CROSS-SECTION AT WESTMONT PIER NO. 17

FIGURE H-4. PATCO ELEVATED STRUCTURE TRACK SUPPORT

The day-night average sound level, L_{dn}, can be calculated by summing the sound energy of all train passbys, with a 10 dB penalty added to nighttime (10:00 p.m. to 7:00 a.m.) operations, and averaging the result over a 24-hr period. The L_{dn} may be calculated from:

$$L_{dn}(15\text{ m}, 1\text{ car}) = \text{SENEL}(15\text{ m}, 1\text{ car}) + 10\log(n_{day} + 10n_{night}) - 49.4, \tag{H.1}$$

where L_{dn}(15 m) is the day-night average sound level, in dB, at a distance of 15 m (50 ft). SENEL(15 m, 1 car) is the single event noise exposure level, in dBA, for a single-car passby at a distance of 15 m (50 ft). n_{day} is the number of transit cars during daytime (7:00 a.m. to 10:00 p.m.), and n_{night} is the number of transit cars during nighttime (10:00 p.m. to 7:00 a.m.).

Based on PATCO schedule data [*H.2*, *H.3*], the L_{dn} is found to be:

$$\begin{aligned} L_{dn}(15\text{ m}) &= 74\text{ dB at 97 km/h (60 mph)} \\ &= 69\text{ dB at 56 km/h (35 mph)} \\ &= 64\text{ dB at 32 km/h (20 mph).} \end{aligned}$$

L_{dn} values for locations beyond 15 m (50 ft) are calculated assuming a decrease corresponding to 10 log distance.

H.3 Fractional Impact Analysis

The fractional impact analysis here is accomplished by the method outlined by Schultz [*H.4*], described on page H-7:

1. The transit L_{dn} component is estimated at distances corresponding to the first row of residential buildings. These distances range between 7.6 and 137 m (25 and 450 ft), based on BBN observations. Train speeds for this estimate are chosen based on the distance from the stations along the transit corridor, as described above.

2. Ambient noise levels (without PATCO) are estimated based on population density data [*H.5*] using the relation [*H.6*]:

$$L_{dn} = 10 \log (\rho) + 22 \text{ dB}, \tag{H.2}$$

where ρ denotes population density (people per square mile). Based on population densities of 7,500-17,500 people per square mile [*H.5*], the ambient levels (L_{dn}) are estimated to be 60 to 65 dB in the vicinity of the PATCO elevated structures.

3. Residential locations at which the transit noise is more than 5 dB below the ambient noise are eliminated from the impact analysis.

4. It is assumed that there are an average of three people per residential unit. A total of approximately 260 residential units is impacted. The impacted population is reduced by one-half as suggested by Schultz [*H.4*], to account for the assumption that only that half of the people that face the tracks are significantly impacted.

5. The total Sound Level Weighted Population (LWP) is calculated by summing the products of the number of people times the noise weighting function (W) corresponding to the transit L_{dn} at each residential location.

The results of the fractional impact analysis for the PATCO system indicate a total Sound Level Weighted Population (LWP) of 147, for a total impacted population of 392.

REFERENCES – APPENDIX H

H.1 Hanson, C.E. *et al.*, "Noise Control for Rapid Transit Cars on Elevated Structures: Preliminary Investigation of Vehicle Skirts, Undercar Absorption, and Noise Barriers," BBN Rept. 4155 (January 1980).

H.2 PATCO, Timetable (Winter-Spring 1979).

H.3 Wolfe, D.R., PATCO, private communication (June 1979).

H.4 Schultz, T.J., "Noise Rating Criteria for Elevated Rapid Transit Structures," BBN Rept. No. 3905 (April 1979).

H.5 Chisholm, G. *et al.*, "National Assessment of Urban Rail Noise," U.S. Department of Transportation, Urban Mass Transportation Administration, Rept. No. UMTA-MA-06-0099-79-2 (March 1979).

H.6 U.S. Environmental Protection Agency, "Population Distribution of the United States as a Function of Outdoor Noise Level," Rept. No. EPA-550/9-74-009-A (June 1974).

APPENDIX I: SEPTA INVENTORY

I.1 Elevated Structure Description

The Southeastern Pennsylvania Transportation Authority (SEPTA) rail transit system contains approximately 12.4 km (7.7 miles) of elevated structure, located along the Market-Frankford line in Philadelphia (see Fig. I-1).

The Market St. section includes about 3.9 km (2.4 miles) of elevated structure between Millbourne St. and 44th St. The predominant structure design for this section consists of transverse steel plate beams, supported by two longitudinal lattice web girder stringers, 1.7 to 1.8 m (5.5 to 6 ft) in depth, which span typically 15 m (50 ft) between steel bents (see Fig. I-2). Jointed rail on wood ties and ballast is carried on a concrete deck atop solid steel plate, which is supported by the transverse beams (see Fig. I-3). A 366 to 427 m (1200 to 1400 ft) section of the Market St. line, between 63rd St. and Millbourne St., consists of a structure with wood ties supported directly on longitudinal lattice web girders. Since this segment is of minimal length, and since there is no residential land use along this portion of the line, the open deck section is not considered as a separate case in the present impact analysis.

The Frankford section includes elevated structure between the Spring Garden and Bridge-Pratt St. stations, a distance of about 8.5 km (5.3 miles). The predominant structure for this section consists of transverse steel lattice web girders, supported by three longitudinal lattice web girder stringers, 1.8 m (6 ft) in depth, which span typically 15.8 m (52 ft) between steel bents (see Fig. I-4). The bents are supported either by

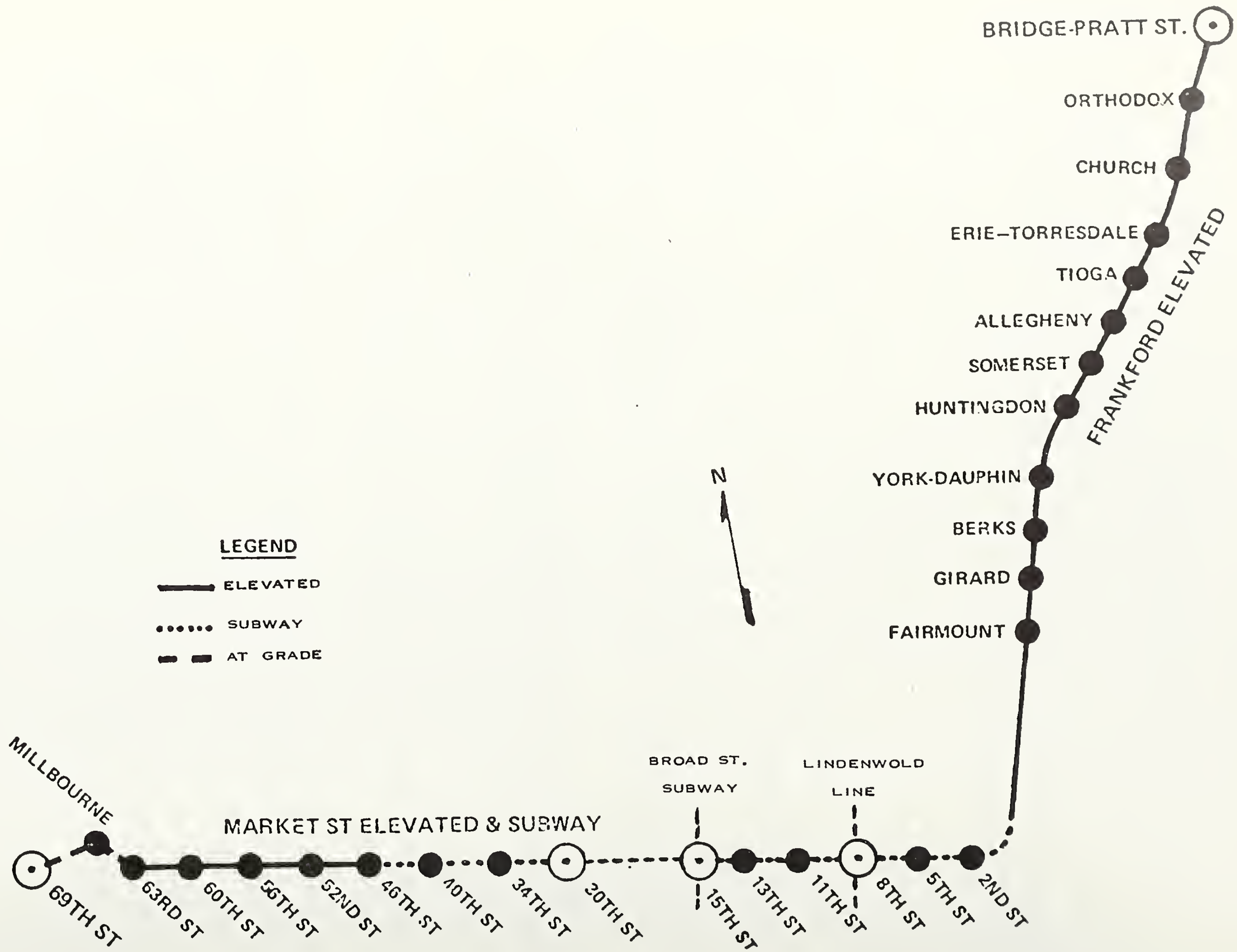


FIGURE I-1. SEPTA MARKET - FRANKFORD SYSTEM SCHEMATIC

FIGURE I-2. SEPTA MARKET ST. LINE ELEVATED STEEL STRUCTURE

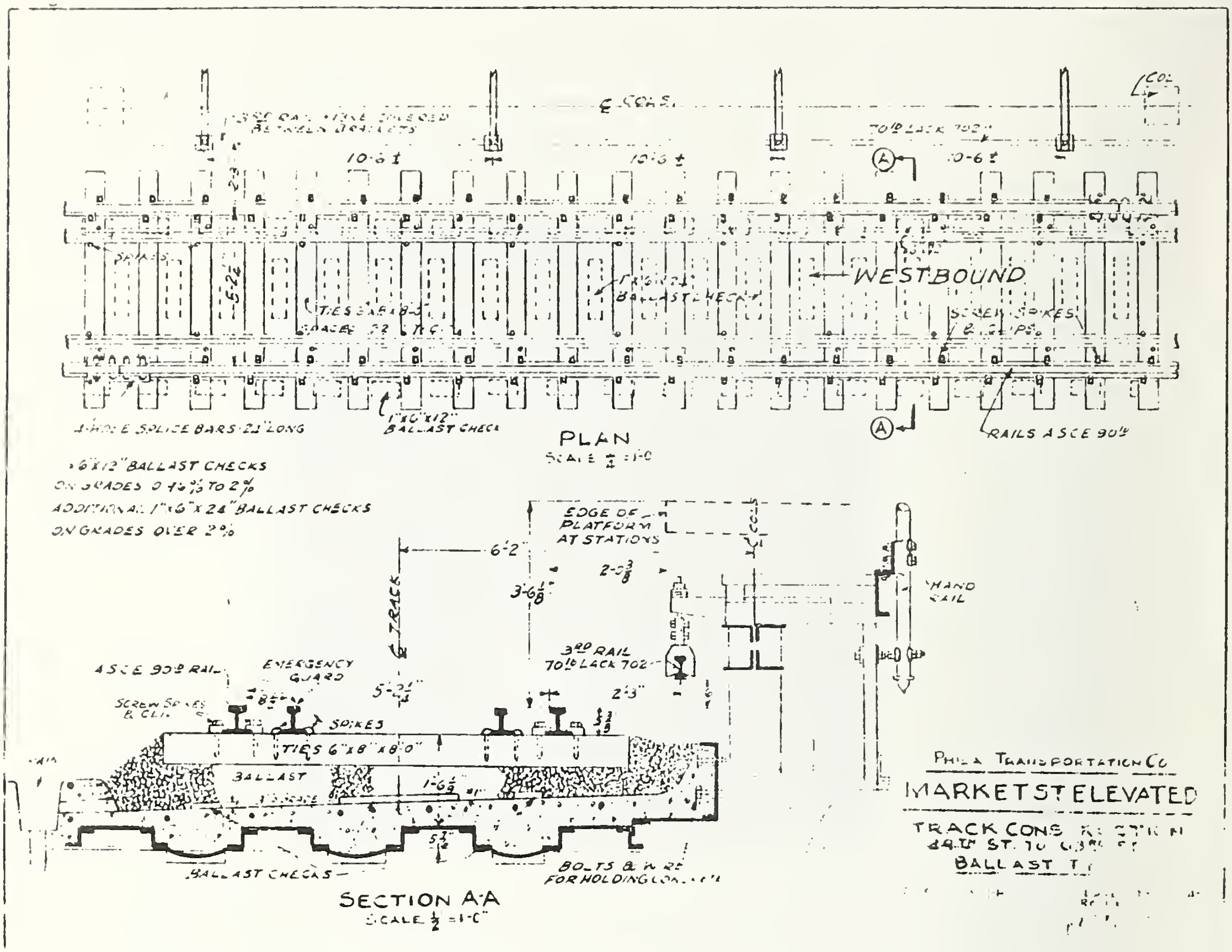


FIGURE I-3. SEPTA MARKET ST. LINE ELEVATED STEEL STRUCTURE TRACK CONSTRUCTION

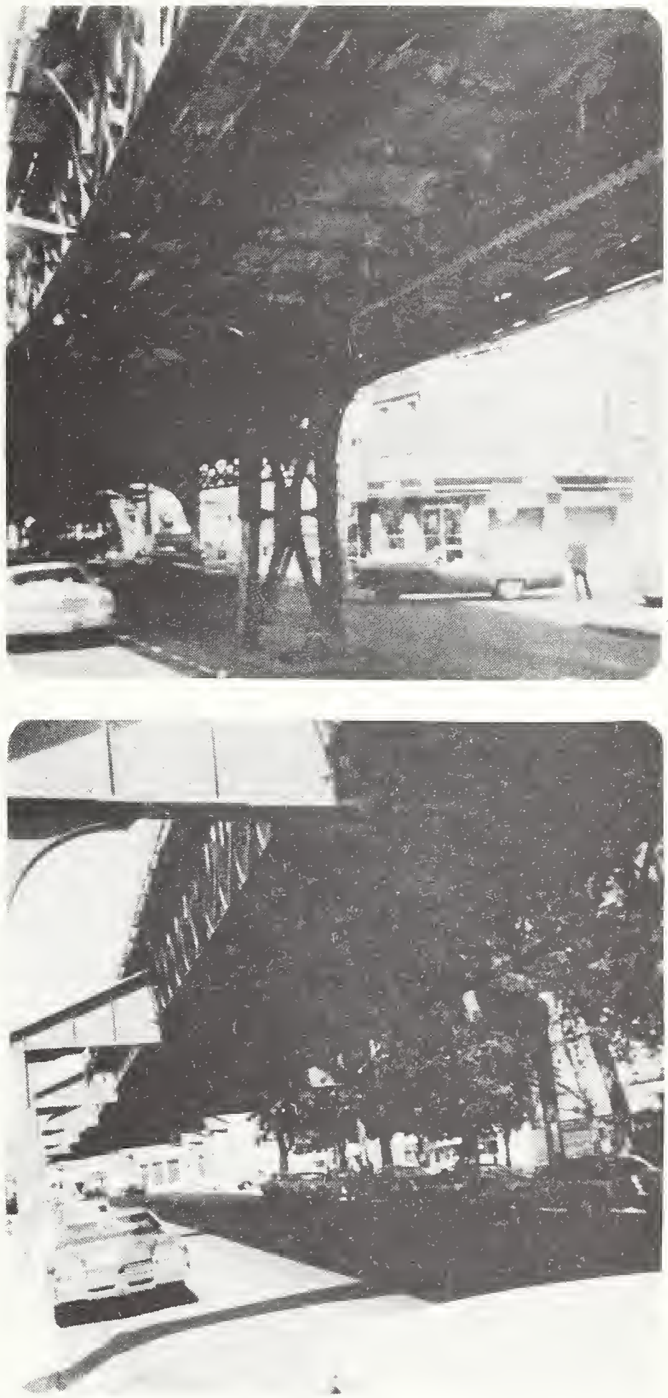


FIGURE I-4. SEPTA FRANKFORD LINE ELEVATED STEEL STRUCTURE

two columns or a single center support. The track consists of jointed rail on wood ties and stone ballast, on top of a concrete deck that is supported by the transverse beams (see Fig. I-5). Rail pads of some type of rubber fabric have been installed between the rails and ties in some sections, where upgrading has been done. Such sections include at most 0.8 km (0.5 miles) of the Frankford line steel structure and are not considered as a separate case for the present analysis.

A new 0.8 km (0.5 mile) section of the Frankford line consists of a concrete viaduct (see Fig. I-6). Here, welded rail is mounted to a concrete deck with resilient fasteners (see Fig. I-7).

I.2 Noise Estimation

The estimation of L_{dn} is based on noise measurements previously conducted by BBN [*I.1*] and by the Boeing Vertol Company [*I.2*].

Noise measurements were conducted by BBN along the Frankford elevated section of the SEPTA system in December 1977, as part of an environmental noise assessment for reconstruction of this line [*I.1*]. The measurements were made at 30 m (100 ft) from the structure centerline, 1.5 m (5 ft) above the ground, for typical near and far track 6-car train passbys at 48 km/h (30 mph). The resulting single event noise exposure levels (SENEL) are summarized as follows.

Frankford Elevated Steel Structure:

SENEL at 30 m (100 ft) = 94 dBA (near track, average of 7 measurements)
= 89 dBA (far track, average of 7 measurements).

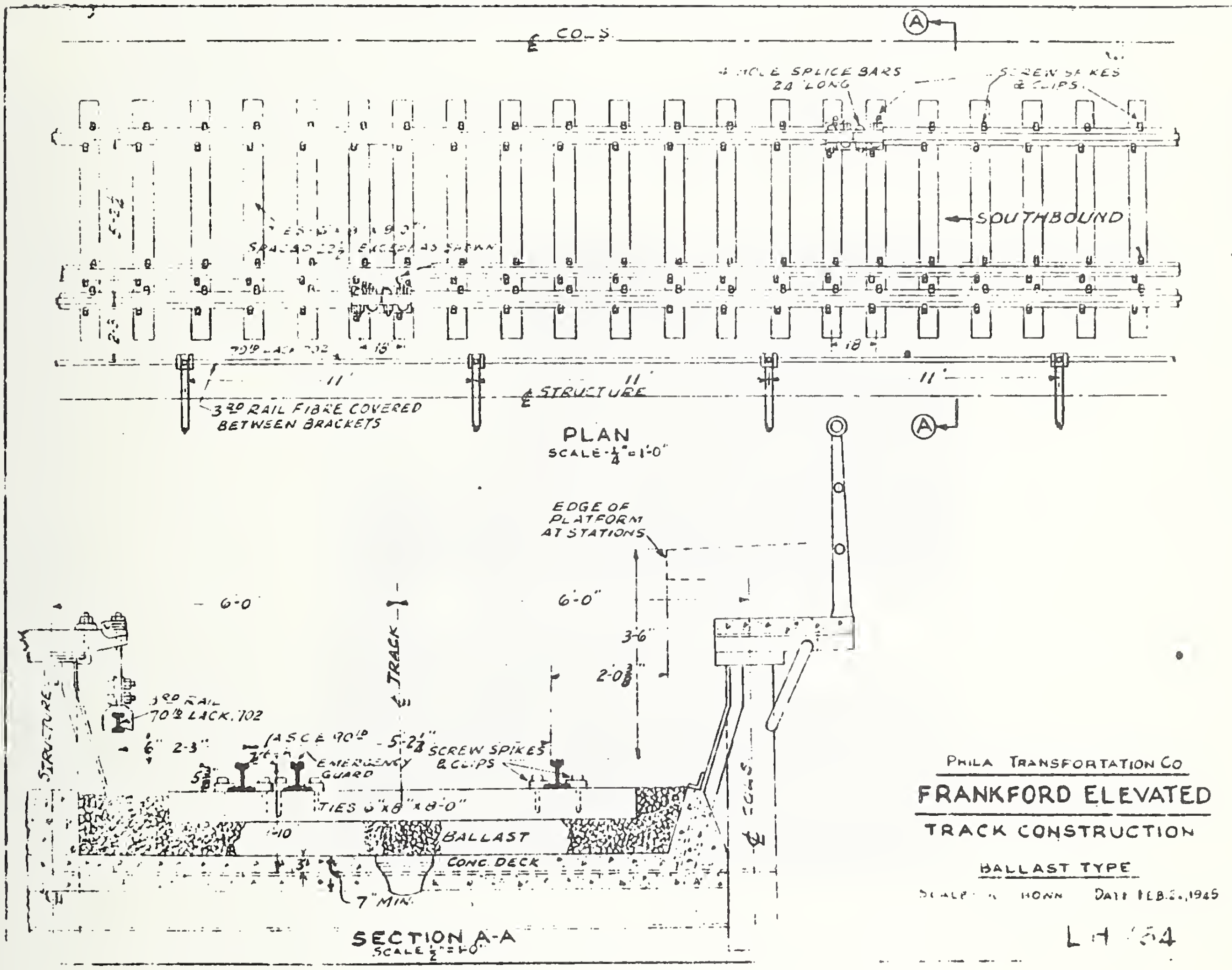


FIGURE I-5. SEPTA FRANKFORD LINE ELEVATED STEEL STRUCTURE TRACK CONSTRUCTION

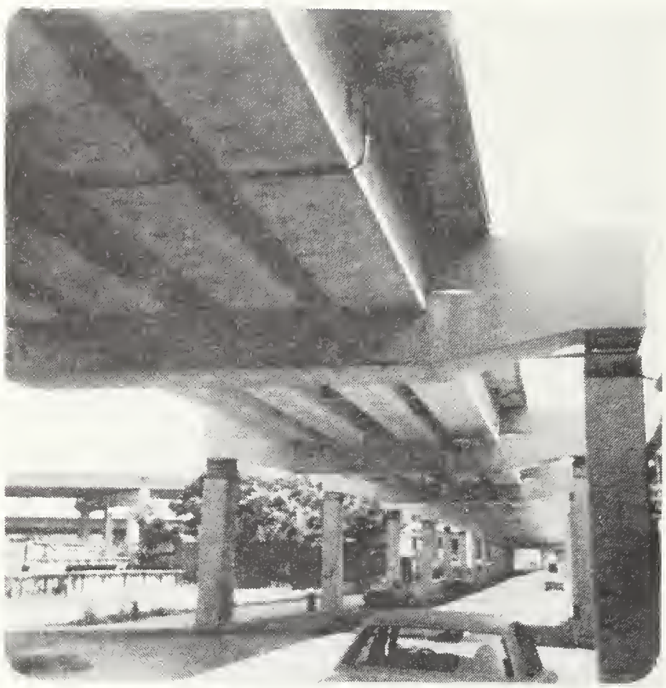


FIGURE I-6. SEPTA FRANKFORD LINE CONCRETE VIADUCT

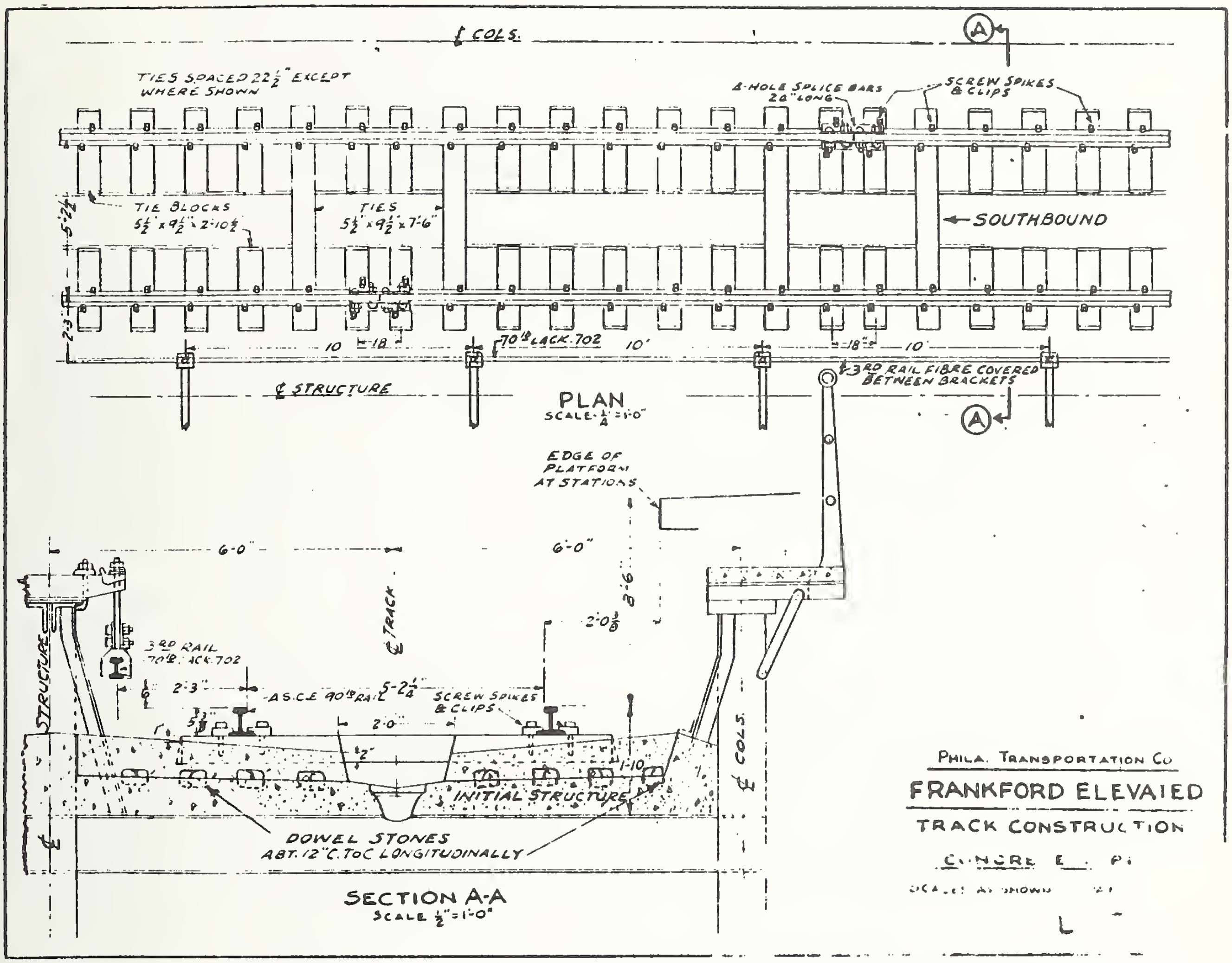


FIGURE I-7. SEPTA FRANKFORD LINE CONCRETE VIADUCT TRACK CONSTRUCTION

Frankford Elevated Concrete Viaduct Structure:

SENEL at 30 m (100 ft) = 90 dBA (near track, average of 3 measurements)
= 88 dBA (far track, average of 5 measurements).

The Boeing Vertol Company conducted noise measurements adjacent to steel elevated structures on both the Frankford and Market St. sections of the SEPTA system [*I.2*]. A-weighted time histories of both near and far track train passbys were used to determine both the Average Maximum Level, L_A(Max), and the duration T_5 (in seconds) of each noise event, taken as the time that the noise level was within 5 dB of L_A(Max). The duration was used to calculate the parameter L_R from:

$$L_R = L_A(\mathrm{Max}) + 10 \log T_5 \quad , \mathrm{dBA} \quad ,$$

where L_R is an approximation to SENEL suggested by Schultz [*I.3*]. The Boeing measurements were made at 15 m (50 ft) from the elevated structure, 1.6 m (5.25 ft) above the ground, for typical six-car train passbys. The resulting SENEL estimates are summarized as follows, normalized to 30 m (100 ft).

Frankford Elevated Steel Structure:

SENEL at 30 m (100 ft) ≃ 93 dBA (near track, average of 4 measurements)
≃ 89 dBA (far track, average of 4 measurements).

Market St. Elevated Steel Structure:

SENEL at 30 m (100 ft) ≃ 93 dBA (near track, average of 4 measurements)
≃ 89 dBA (far track, average of 4 measurements).

The preceding Boeing results indicate that train passbys generate the same acoustic energy on both the Frankford and Market St. elevated steel structures, despite the structural design differences. Furthermore, the Boeing results for the Frankford steel elevated structure are seen to agree closely with the BBN measurements. Therefore, the BBN SENEL results obtained for the Frankford line elevated steel structure were used for noise impact analysis for all SEPTA steel elevated structures. Additionally, the BBN results for the Frankford line concrete viaduct segment were used to characterize noise from this structure.

The day-night average sound level, L_{dn}, calculated by summing the sound energy of all train passbys with a 10-dB penalty added to nighttime (10 p.m. to 7 a.m.) operations, and averaging the result over a 24-hr period, may be computed from:

$$L_{dn}(30\text{ m}) = \text{SENEL}(30\text{ m}) + 10 \log [N_{day}+10N_{night}] - 49.4, \tag{I.1}$$

where $L_{dn}(30\text{ m})$ is the day-night average sound level, in dB, at a distance of 30 m (100 ft); SENEL(30 m) is the single event noise exposure level for a typical train passby at 30 m (100 ft), in dBA; N_{day} is the number of train passbys between 7 a.m. and 10 p.m.; and N_{night} is the number of train passbys between 10 p.m. and 7 a.m.

Information obtained during the Frankford Elevated noise assessment [*I.1*] indicates 192 daytime and 32 nighttime train passbys per day in each direction. Based on these numbers and the measured BBN SENEL data, the near track and far track L_{dn} components for the two basic structure types were calculated using Eq. I.1. Logarithmic addition of the near and far track L_{dn} components yields the following results:

SEPTA Elevated Steel Structure:

L_{dn} at 30 m (100 ft) = 73 dB [for six-car trains at 48 km/hr (30 mph)]

SEPTA Elevated Concrete Viaduct:

L_{dn} at 30 m (100 ft) = 70 dB [for six-car trains at 48 km/h (30 mph)].

L_{dn} at distances other than 30 m (100 ft) may be estimated by assuming the L_{dn} varies as 10 log (1/distance).

I.3 Fractional Impact Analysis

The fractional impact analysis for the SEPTA system elevated structures is accomplished by the method outlined by Schultz [*I.4*], using the following steps:

1. The transit L_{dn} component is estimated, as previously outlined, for distances corresponding to the first row of residential and commercial buildings. These distances are obtained from a physical inventory [*I.5*].
2. The population for each block along the elevated lines is obtained from the physical inventory [*I.5*], which determined an average of 0.2 people per ft of frontage per story.
3. The Sound Level Weighted Population (LWP) for each segment between elevated line stations is calculated by multiplying the population bordering the segment by the noise weighting function (W) corresponding to the transit L_{dn} for the appropriate structure type at each residential/commercial location.

4. The total LWP is calculated for each elevated line, for each structural type, and for the entire system, by summing the LWPs for the appropriate station-to-station segments. Results are obtained for the following two cases: (a) residential and commercial land uses impacted and (b) only residential land uses impacted.

The above procedure assumes that train noise is never more than 5 dB below the ambient L_{dn} (without trains) at the first row of buildings. The lowest train L_{dn} component encountered in the calculations is 72.5 dB. Population data indicate that population densities along the Market-Frankford elevated line range between 550 and 37,500 people per square mile [*I.6*]. Ambient noise levels, estimated from the relation [*I.7*], L_{dn} = $10 \log(\rho) + 22$ dB [where ρ denotes the population density (people per square mile)], turn out to range between 49 and 68 dB. Therefore, the fractional impact analysis should include all areas exposed to a train L_{dn} component of 63 dB or greater. Since the lowest train noise encountered was 72.5 dB, the assumption of train noise dominance is considered justifiable.

The results of the fractional impact analysis for the SEPTA system elevated structures are summarized in Tables I-1 and I-2. Calculation details, including station-to-station noise impact data, are provided in Table I-3.

TABLE I-1. SEPTA SYSTEM ELEVATED STRUCTURE FRACTIONAL IMPACT ANALYSIS SUMMARY

Elevated Line	Structure Type	Impacted Population		Sound Level Weighted Population (LWP)	
		Residential & Commercial	Residential Only	Residential & Commercial	Residential Only
Market St. Section	Steel with lattice web girder stringers, jointed rail, wood tie and ballast on steel and concrete deck	13,333	10,018	13,807	10,087
Frankford Section	(a) Steel with lattice web girder stringers, jointed rail, wood tie and ballast on concrete deck	24,623	16,752	31,752	22,122
	(b) Concrete viaduct, welded rail with resilient fasteners on concrete deck	980	980	931	931
	(c) Total line	25,603	17,732	32,683	23,053
Market St. and Frankford Sections	Steel structure	37,956	26,770	45,559	32,209
Frankford Section	Concrete Viaduct	980	980	931	931
ALL LINES	ALL TYPES	38,936	27,750	46,490	33,140

TABLE I-2. POPULATION VS NOISE EXPOSURE FOR SEPTA SYSTEM ELEVATED STRUCTURES

Elevated Line	Structure Type	No. of People Exposed to Elevated Transit Structure Noise Within Various Ranges of L_{dn}, in dB — Residential & Commercial 70 – 75	Residential & Commercial 75 – 80	Residential & Commercial 80 – 85	Residential Only 70 – 75	Residential Only 75 – 80	Residential Only 80 – 85
Market St. Section	Steel with lattice web girders, tie and ballast, and steel/ concrete deck	3,998	9,335	-	3,763	6,255	-
Frankford Section	(a) Steel with lattice web girders, tie and ballast and concrete deck	-	23,290	1,333	-	16,066	686
	(b) Concrete viaduct, welded rail with resilient fasteners on concrete deck	490	490	-	490	490	-
	(c) Total line	490	23,780	1,333	490	16,556	686
Market St. and Frankford	Steel structure	3,998	32,625	1,333	3,763	22,321	686
Frankford	Concrete viaduct	490	490	-	490	490	-
ALL LINES	ALL TYPES	4,488	33,115	1,333	4,253	22,811	686

TABLE I-3. SEPTA NOISE IMPACT CALCULATIONS

Elevated Structure Location and Description	Approx. Segment Length (ft)	Distance to Bldgs. (ft)	Transit L_{dn} (dB)	W (L_{dn})	Impacted Population (P)		Sound Level Weighted Population (LWP)	
					Residential & Commercial	Residential Only	Residential & Commercial	Residential Only
Market St. Section								
Steel Structure								
Abutment - 46th St.	1,150	40	76.5	1.118	920	920	1,029	1,029
46th St. - 52nd St.	3,300	30	77.5	1.202	188	--	226	--
		40	76.5	1.118	1,692	1,504	1,892	1,681
		60	75.0	1.000	470	--	470	--
		100	72.5	0.822	3,763	3,763	3,093	3,093
Subtotal					6,113	5,267	5,681	4,775
52nd St. - 56th St.	2,200	40	76.5	1.118	1,760	1,056	1,968	1,181
56th St. - 60th St.	2,200	40	76.5	1.118	2,200	1,650	2,460	1,845
60th St. - 63rd St.	1,800	40	76.5	1.118	1,710	1,125	1,912	1,258
63rd St. - Abutment	2,100	30	77.5	1.202	630	--	757	--
TOTAL SECTION	12,750				13,333	10,018	13,807	10,087
Frankford Section								
Steel Structure								
Bridge St. - Orthodox	3,300	10	81.0	1.526	132	--	201	--
		15	80.0	1.428	132	--	189	--
		23	78.5	1.289	1,980	1,320	2,552	1,701
Subtotal					2,244	1,320	2,942	1,701
Orthodox - Church	2,300	15	80.0	1.428	368	--	523	--
		23	78.5	1.289	1,196	552	1,542	712
		25	78.0	1.245	823	363	1,025	452
Subtotal					2,387	915	3,090	1,164
Church - Tioga	6,550	23	78.5	1.289	2,620	2,245	3,377	2,894
Tioga - Allegheny	2,500	23	78.5	1.289	2,800	1,800	3,609	2,320
Allegheny - Somerset	3,300	23	78.5	1.289	3,740	2,420	4,821	3,119
Somerset - York/Dauphin	3,700	12	80.5	1.476	634	422	936	623
		15	80.0	1.428	634	528	905	754
		23	78.5	1.289	2,708	1,754	3,491	2,261
Subtotal					3,976	2,704	5,332	3,638
York/Dauphin - Girard	3,700	18	79.0	1.384	1,816	1,211	2,513	1,676
		20	79.0	1.384	2,270	1,867	3,142	2,584
		23	78.5	1.289	2,770	2,270	2,926	2,926
Subtotal					6,856	5,348	8,581	7,286
Total Steel Structure	25,350				24,623	16,752	31,752	22,122
Concrete Structure								
Girard - Spring Garden	2,450	20	76.0	1.078	490	490	528	528
		50	72.5	0.822	490	490	403	403
Total Concrete Structure	2,450				980	980	931	931
TOTAL SECTION	27,800				25,603	17,732	32,683	23,053
TOTAL LINE	40,550				38,936	27,750	46,490	33,140

REFERENCES – APPENDIX I

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APPENDIX J: WMATA INVENTORY

J.1 Elevated Structure Description

The Washington Metropolitan Area Transit Authority (WMATA) system currently operates on approximately 7 km (4.5 miles) of elevated structure, with an additional 5 km (3 miles) of such structure planned for future use. The WMATA system includes a variety of elevated structure types as follows:

1.	Steel plate girder, concrete slab deck, welded rail with resilient fasteners;	1.6 km (1.0 miles)
2.	Steel box girder, concrete slab deck, welded rail with resilient fasteners;	8.0 km (5.0 miles)
3.	Concrete box girder, concrete slab deck, wood tie and ballast, welded rail;	2.0 km (1.2 miles)
4.	Concrete box girder, concrete slab deck, welded rail with resilient fasteners;	0.6 km (0.4 miles)
	TOTAL:	12.2 km (7.6 miles)

The WMATA system is new, relatively quiet, and generally not near residential areas.

J.2 Noise Estimation

Noise data provided by WMATA [*J.1*] suggest that the maximum noise level for a typical 6 to 8 car train passby at 120 km/h (75 mph) is 80 dBA at 30 m (100 ft).

The approximate conversion from maximum (peak) sound level, L_{max}, to single event noise exposure level, SENEL, is accomplished by use of the following equation [*J.2*]:

$$SENEL(d) = L_{max}(d) + 10 \log \left[\frac{11.3d}{v}\right], \qquad (J.1)$$

where SENEL(d) is the single event noise exposure level, in dBA, at distance d; $L_{max}(d)$ is the maximum (peak) passby noise level, in dBA, at distance d; d is the distance to track centerline, in m; and v is the train speed, in km/h.

Application of this equation to WMATA yields:

SENEL(30 m) = 85 dBA (120 km/h, six to eight cars).

The day-night average sound level, L_{dn}, may be calculated from:

$$L_{dn}(30\ m) = SENEL(30\ m) + 10 \log [N_{day} + 10N_{night}] - 49.4, \qquad (J.2)$$

where $L_{dn}(30\ m)$ is the day-night average sound level, in dB, at 30 m (100 ft); SENEL (30 m) is the single event noise exposure level, in dBA, at 30 m (100 ft); N is the number of train passbys in daytime (7 a.m. to 10 p.m.); and N_{night} is the number of train passbys in nighttime (10 p.m. to 7 a.m.).

Based on WMATA schedule data [*J.1*], one finds an L_{dn} of 64 dB at 30 m (100 ft) from the elevated structure. L_{dn} beyond 30 m is calculated assuming attenuation as 10 log (distance).

J.3 Fractional Impact Analysis

Information provided by WMATA [*J.1*] suggests that the ambient noise between train passages is 60 dBA or more; thus, the ambient L_{dn} is at least 60 dB. WMATA data [*J.1*] indicate that residential

zones are 300 m (1000 ft) or more from the elevated structures. The transit system L_{dn} at 300 m (1000 ft) is estimated to be 54 dB and, thus, is more than 5 dB below the ambient noise level. Therefore there essentially is no noise impact from the WMATA elevated structures [*J.3*].

REFERENCES – APPENDIX J

J.1 Chen, H.M. (WMATA), letter to E. Ungar (BBN), (15 January 1979).

J.2 U.S. Department of Transportation, "Final Environmental Impact Statement – Orange Line Relocation and Arterial Street Construction (Southwest Corridor Project)," UMTA Project No. MA-23-9007, FHWA Project No. U-393(1), Appendix H (March 1978).

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APPENDIX K: REPORT OF NEW TECHNOLOGY

The work performed under this contract has led to an innovative analysis technique, called the "Fractional Import Method", and applied to assess the environmental noise impact of rapid rail elevated structures.

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